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Whither Harwell?

WHILST considerable attention has been paid to the reorganization of the Industrial Group into Production, and Development and Engineering, and the fields of operation of these two groups more precisely defined, the Atomic Energy Research Establishment at Harwell has progressively become more and more isolated from the central themes of atomic energy development, and its contribution to the overall programme more and more ephemeral. Over the years, senior staff with a wide experience in the field have moved away from Harwell and replacements have been difficult to come by; even the present director is only 15 months off retirement age. The integrated expertise of the establishment is steadily decreasing and although the superficial explanation is that one of Harwell's functions is to provide a training ground for nuclear scientists and engineers or alternatively that salary scales are inadequate, these are not the real causes. Staff leave Harwell because they are dissatisfied with the type of work, the organization or the general tempo. Furthermore, only in the very highest brackets are salary scales below those paid outside; opportunities for promotion may have been greater elsewhere, for example, in the Industrial Group but this again reflects the tempo of the work rather than any fundamental difference in salary scaling. At intermediate levels salaries in the Authority are in general higher than those paid in industry for equivalent responsibilities and considerably higher than those that can be afforded by the Universities.

The flux of people from Harwell reflects not financial inadequacy but inadequacy of purpose in the establishment, a feeling of frustration with the somewhat overbearing administration and a consciousness of being divorced from the main stream of atomic energy development. This is a far cry from the days in the late forties when Harwell was the most glamorous research establishment in Europe and when the mere name conjured up the most dynamic development programme of this century.

But today, to the questions "What are Harwell's proper functions in the present programme?" "What is the central theme of the establishment?" "Which are the most important projects?" there appears to be no answer. The one field of research which could provide the necessary stimulus—the controlled thermonuclear project—is to be moved to a new establishment. Of the two people whose names were most frequently linked with ZETA, one is now director of Winfrith, the other is in America on a protracted visit. The new leader of the group returns from CERN to find that in effect the CTR has now no home.

Nuclear physics, which since 1945 has been centred on AERE is now moved down to Winfrith and the more exciting and far-reaching experiments on high-temperature systems will be handled there. The long term programme for the whole Winfrith establishment is by no means worked out but at least ZENITH is complete and is being commissioned, the DRAGON team is building up and the whole high temperature gas-cooled project is gathering impetus. There is an excitement in the atmosphere at Winfrith, reminiscent of the early days at Harwell. This is partly the result of opening a new site but it also stems from working for a definite target and from a determination not to make the same mistakes.

Other centres of research in the country which are going from strength to strength include the Dounreay Works where the fast reactor project is now regarded as carrying the highest priority for "third stage" systems whilst on the same site a considerable programme of work is associated with the DMTR and with the enriched fuel preparation and processing lines. The most immediate reactor development project, AGR, is firmly under way at Windscale, wherein is centred the heavy responsibility for producing a system which will represent a significant advance over the Calder family. The various other research facilities of the D and E Group are being built up and an intensive programme worked out, which will stretch the resources of the Group to the limits. Production Group research effort is also being increased and the transfer of specific responsibility to the works managers should lead to a further rise in tempo at the factory sites. At Wantage the Technological Irradiation Group has defined its main avenues of research and is settling down to a long-term investigation of irradiation damage effects. Meanwhile, the research departments of the consortia are gaining not only in strength but in experience, and at Berkeley the Generating Board is establishing laboratories which, once operational, will assume a growing importance particularly in the field of operational research. Although only the corner has been lifted of the veil over AWRE at Aldermaston, we have seen that a large accelerator division has been formed and there are indications that the fundamental work being done on beryllium and plutonium will have an important bearing on future reactor developments. There are no signs yet of any decrease in the military functions of this establishment but the possibility of

more research facilities becoming available for civilian applications cannot be ignored.

The position then is this: the second stage of reactor developments is based on Windscale and the third stages on Dounreay and Winfrith, the CTR project is floating, the Irradiation Centre is at Wantage and Isotope production at Amersham, research for fuel production and processing is on the factory sites. Where into this picture does Harwell fit?

As regards experimental facilities the laboratories at Harwell are second to none in the country. LIDO, DIDO and PLUTO not to mention BEPO and GLEEP are located there, but other experimental facilities such as NERO and NEPTUNE are likely to move south shortly. Geographically, AERE was well placed; not as attractive a site as Winfrith but comfortably positioned to act as the pivot for the bulk of atomic energy research. But, without any central project on which to hinge this research, and with a staff depleted of senior men and its more progressive younger people, the facilities cannot be exploited.

The history of many of the divisions into which Harwell was split is an unhappy one; only the Chemistry division can really claim to have maintained a continuous purposeful progress based on a continuing chain of loyalty. The saddest story, perhaps, concerns the Engineering division which has several times been split and regrouped and which, since the building of BEPO, has not been able to concentrate on a single major AEA building project. The function of engineers is not just to design but to build and the absence of specific projects at Harwell has, as a result, damaged the Engineering division more than any other. The only large-scale project with which the division has been concerned since BEPO is the proton synchrotron and this is not an AERE, but a National Institute, venture.

Perhaps in the National Institute's NIMROD lies the ultimate focus for the Establishment—the large research tool which will attract the best men and form a gravitational point around which the rest of the Establishment can revolve.

In theory at least, the prime function of Harwell was to undertake fundamental research in the atomic energy field and there are many who feel that the real mistake that had been made was to fall between the stools of fundamental research on one side and applied research or development work on the other. These members would advocate a return to a more university-style atmosphere and even talk about the good old days under the Ministry of Supply—a somewhat ironic comment when one remembers the colourful pictures painted when the breakaway from the Ministry was first mooted. No one denies that a heavy programme of fundamental work is desirable but there is a difference between random research and research centred around specific projects with effective channels of communication between the research worker and the development engineer. There is little doubt also that the best fundamental work is done when the individual has a large say in the choosing of the project and in the manner in which it is carried out. At the same time there is equally little doubt that the investment and scale of the work necessary can no longer be handled by the Universities. But what also seems clear is that if Harwell is to become a "pure" (as opposed to applied) research establishment, then its facilities should be available to a wider sphere of activity than simply atomic energy, and its very considerable cost should not be borne, even nominally, by the Atomic Energy Authority. Similarly research workers should not be hampered by an administrative system which would appear more suited to a Government armament factory, not to mention the self-conscious security restrictions (whether the classifying is deemed military or commercial).

Even if Sir William Penney can pull off the (what at the present time looks impossible) task of regenerating morale at Harwell and defining and organizing its functions so that not only can it provide, but know that it is providing, a useful service to the atomic energy industry, can we, with the relatively modest construction programme at present forecast, justify the overhead of all these various research establishments? If we had been full-time members of the Euratom community then a convenient solution was at hand; this could become the northern centre for the community and its overheads spread over the seven countries. There is still room for such a move to be made within the OEEC framework but the difficulties would be immense.

Perhaps we underestimate the work that is being done at Harwell—but so also apparently does most of the rest of the country including the Authority's own staff and this would imply a strong criticism of the channels of communication leading out of AERE. But, if this is not the case, Harwell still cannot just be abandoned; too much capital is tied up in the Establishment and, however regrettable the siting of the reactors might be, it is still the largest materials testing centre in the country. Should the PLUTO and DIDO site be hived off, and become an irradiation facility serving the other Groups and the country as a whole? Should NIRNS steadily infiltrate and take the Establishment under its wing? Should Harwell become a separate national research centre under a new body? Or should it be carved up and serve as out-stations to the other sections of the Authority? It seems ironic, at this juncture, that the Development and Engineering Group should be forcibly limited to an annual 8% increase in staff when it is taking on such a great deal of extra work, whilst Harwell could have development capacity to spare. Whatever decision is taken by the Authority as to the future of Harwell this decision must be taken soon, or the standard of morale will be beyond recall. The immediate and ultimate future of the Establishment is probably the most thorny problem that Sir Roger Makins will have to face when he takes up office at the end of the year, unless, of course, he is forestalled by Viscount Hailsham. Would it be too revolutionary to suggest that Harwell should become the new centre for controlled thermonuclear research and high energy physics and that the IAEA be encouraged to set up any international CTR laboratory there?

DIGEST...

Surveying Significant News

Viscount Hailsham Takes Responsibility for Science Projects in Next Parliament

The AEA, amongst other Government sponsored technical organizations, is answerable to Parliament through Viscount Hailsham. Previously the AEA reported directly to the Prime Minister. This devolving of responsibility will allow the Government more time to consider current problems and should allow some rationalization of the independent organizations that exist up and down the country. How far-reaching this will be will depend very much on whether Viscount Hailsham can reconcile the varied interests of the bodies and individuals concerned. Certainly the post is no sinecure, but we wish him a success in this campaign equal to that which he has just recorded in his former position as Chairman of the Conservative Party.

A.P.C. and G.E.C. Consortia to Collaborate on Future Power Station Projects

The anticipated link-up between Atomic Power Constructions and G.E.C., Simon-Carves has now been confirmed. The two groups will in future submit joint tenders for power stations, and research and development effort will be shared. Prior to the preparation of a tender the two concerns will by mutual agreement allocate construction responsibilities between the component companies. This will be arranged partly on a capacity basis, partly on a "fair shares for all" system and partly on the price estimates submitted by the companies. The joint tender will thus include components to be manufactured by most, if not all, of the companies comprising the groups. Research and development teams will not be cut down but reorganized to cover a more complete range of experimental work.

Warsaw Conference Points Need for Fundamental Research

The Warsaw Conference on the application of high energy radiation sources will have brought little comfort to those who anticipated an immediate large-scale use in the chemical industry. Whilst the technique of sterilization, particularly of medical equipment, seems poised for a rapid expansion, a much greater understanding of the mechanism of radiation damage seems necessary before applications in the chemical industry become widespread. The former somewhat *ad hoc* approach is likely to be replaced by a more systematic study of radiation-induced effects, so that a clearer understanding of the fundamental processes can be obtained.

Motherwell Bridge Suspends Work at Hunterston No Date for Resumption Settled

Following a succession of disputes between Motherwell Bridge and their employees (and their unions) on the Hunterston site the company announced on September 25 that operations would be suspended and on September 29 the employees were paid off. A regular succession of unofficial strikes has dogged the construction programme, the final dispute being triggered by the dismissal of a shop steward in the Radiography Group. Reports that the company would now withdraw from the nuclear engineering field are strongly denied, but at the time of going to press—four weeks from the date of the last stoppage—there were still no signs of a reconciliation and no hint could be given of the probable date for resumption of work.

Price of Enriched Material Purchase from U.S. Under Discussion

In regular succession we are seeing published feasibility studies of reactor systems which are dependent upon the use of enriched fuel, as for example the Joint Nuclear Marine Propulsion paper where the case is put for a marine propulsion unit incorporating an organic moderated reactor (p. 412). In cost estimates either American fuel prices are used or arbitrary figures which cannot properly be supported. It is believed that the real cost of enriched material from Capenhurst is something over twice that quoted by the U.S. AEC but no official statement has been made. This factor of two has a material effect on the economics of any system. It is to be hoped that in the very near future when the present talks between the AEA and the U.S. AEC have been concluded price figures can be given which are real. Should we buy American fuel no doubt the terms will be made public, but will there be guarantees that they can be maintained over, say, the life of a ship?

Possibility of CEGB Building 300 MW AGR.

AGR is also receiving the close attention of CEGB. At a Press conference following publication of the annual report Sir Christopher Hinton, chairman of the board, said that a team was studying the possibility of building a prototype 300 MW AGR. The decision to go ahead very much depended on the AEA's final decisions on element canning material; if beryllium is preferred CEGB will wait. We understand that the industry has already been approached and indicated its readiness to submit designs.

Cross-flow Stainless Steel Canned Fuel Element Development

The development of a cross-flow fuel element by G.E.C. (reported in this issue, pages 383 to 385) demonstrates the continuing independent initiative displayed by the U.K. consortia. It is understood that the Authority is interested in the developments and it is to be hoped that appropriate development contracts will be forthcoming and that room will be made in the AEA's programme for an exponential experiment to examine the physics characteristics and also for in-pile tests to be made. The initial charge of the AGR will now be wholly stainless steel canned instead of largely beryllium as was originally designed. Provided initial expectations are fulfilled, it would seem appropriate that one of the experimental channels in AGR be loaded with the cross-flow elements so that direct comparative data can be obtained.

Profit and Loss in Instrumentation

Dowty Nucleonics have followed up the statement made by their chairman at the AGM concerning the limited markets for nuclear instrumentation by announcing their withdrawal from the field. Present contracts—including the supply of the BSD to Berkeley—will be completed and seals and compressors already developed will continue in production. Both Plesseys and Elliotts have been exhibiting their new lines of instrumentation and radiating confidence in the future markets (see pp. 421-424). Whilst Plesseys have been concentrating on their improved BSD designs and range of Radiac equipment, Elliotts have been working towards the complete transistorization of their radiation detection and reactor instrumentation systems based on plug-in units which allow the rapid build-up of any instrument from stock component units. Both these concerns are self-supporting members of larger groups and both foresee a long and profitable future in the nuclear instrumentation field.

Westinghouse Proposals to the Utilities

In a bid to persuade utilities in the United States to begin a constructional programme of nuclear capacity Westinghouse has made proposals for three different lines of attack (see page 411). Suggested installations are a 330 MW all-nuclear saturated steam plant, a 250 MW nuclear boiler with oil-fired superheat or a 20 MW experimental two-zone reactor with one zone providing superheating. Westinghouse are willing to guarantee installation costs, fuel burn-up, and net output. There are signs in the U.S. of the big manufacturers turning back to American high-cost areas as a more profitable market than the European market, where selling has been much tougher than expected, in spite of offers of Government loans and guarantees.

U.S. Uranium Purchases Made Public

The U.S. AEC has made public its yearly purchases of uranium. Statistics on concentrate procurements include annual deliveries from domestic and foreign sources over the 12-year period, 1948 to 1959. This follows the Commission's recent declassification of all data on U_3O_8 production and procurement before July 1, 1955. The overall amount acquired totals nearly 126,000 tons, the 1959 figures being, domestic 15,160 tons and foreign, 18,170 tons.

Canada-Euratom Collaboration

Besides signing an agreement for the exchange of all types of information, materials and equipment with Canada, Euratom have also concluded a technical agreement which provides for the launching of a joint research and development programme centred upon the heavy water moderated reactor type. The agreement calls for the expenditure of $5 million from each party over a period of five years. The community is already collaborating through OEEC in the operation of the Halden reactor, which was officially opened on October 10 by King Olaf of Norway. A Euratom group of manufacturers is soon to pay a visit to Chalk River at the invitation of the Canadian authorities.

JASON Diverges on Schedule

JASON, the 10 kW research reactor built by Hawker Siddeley Nuclear Power at their Langley laboratories, went critical on September 30, exactly within the seven months estimated as the construction time. This is a notable achievement, particularly with a prototype.

G.E.C. Cross-Flow Fuel Element

On their own initiative G.E.C. have been investigating an alternative fuel element design to the rod cluster for highly-rated gas-cooled reactors. The preliminary results on heat transfer and pressure drop reported below show increasing advantages as ratings rise.

Prototype cross-flow fuel element.

AS an alternative to the tube bundles preferred in most designs of fuel elements for highly-rated reactors, whereby the coolant flow is along the axis of the individual rods, the G.E.C. has developed a cross-flow arrangement in which the fuel is enclosed in lenticular tubes mounted transversely to the coolant channel[1]. The first stage of development has concentrated upon the production of a stainless steel clad, UO_2 element suitable for highly-rated reactors of the advanced gas-cooled family in the range 30-100 MW(E). The company has already submitted to the Admiralty designs of a ship-propulsion unit, incorporating a gas-cooled graphite moderated system with a horizontal core based upon this element.

The traditional form of fuel cluster suffers from a number of disadvantages. Because of the poor conductivity of uranium oxide a large temperature gradient is encountered within the rods and the radial thickness must therefore be limited. Fig. 1 plots the maximum diameter of rod tolerable, if the temperature rise within the fuel is maintained at not more than 900°C, against reactor rating. At high ratings, to limit the number of rods (and thus minimize the weight of canning material), tubes can be packed with annular pellets but this introduces the possibility of spalling following cracking and the introduction of high thermal resistance paths. The mechanical strength of the rods is correspondingly adversely affected.

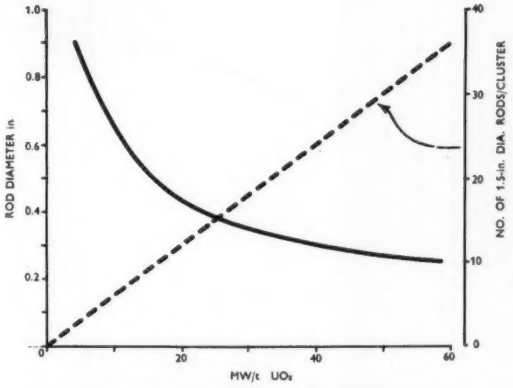

Fig. 1.—Max. rod diameter and number of rods required in a cluster for different fuel ratings if internal temperature rise is not to exceed 900°C.

The support structure for the clusters presents a considerable engineering design problem and inevitably introduces significant pressure losses without contributing to the heat transfer. Designs must effect a compromise between maintaining this pressure loss and the total weight of structural material small whilst preventing bowing of the rods (which distorts coolant flow and restricts the coolant passages) and yet permitting their manufacture to standard tolerances for a moderate cost.

Heat transfer for flow along the axis of a rod is relatively poor and methods of ensuring bulk mixing are liable to introduce further expensive pressure losses. With Magnox, surface finning of the element greatly increases the effective area but due to the low conductivity, stainless steel fins are of little value although some surface roughening may be advantageous.

G.E.C. Development

Development of the G.E.C. element began with circular rods mounted transversely across the channel. Whilst heat transfer is good owing to the two areas of vortex flow around the two down-stream quadrants, pressure losses are high. Data is available for individual elliptical rods placed across the stream[2] but no previous experience has been reported of heat transfer on banks of lenticular or elliptical tubes. A programme of research was, therefore, instituted to determine the characteristics of non-circular sections. Lenticular tubes are commercially available in stainless steel (see Fig. 2) with a wall thickness of 0.010 in. and with a major/minor axis ratio of the order of 3/1. A typical experimental channel for the measurement of heat transfer and pressure drop is shown in Figs. 3 and 4.

With these tubes it was found that whilst heat transfer was not greatly affected by the change in shape, pressure drop was reduced by as much as a factor of four. Fig. 5 compares the relative pressure drops for circular and lenticular tubes (both in cross flow) when the following parameters are maintained constant:

(1) Channel cross sectional area and length.

(2) Surface area of capsule per unit length of channel.

(3) Volume of oxide/unit length of channel.

(4) Channel temperature rise, mass flow and heat output.

In this context a capsule is defined as a single tube containing the oxide pellets. To satisfy conditions (2) and (3) the diameter of the circular rods was adjusted to bring the volume/surface area to the same value as

Fig. 2. — Lenticular tube in stainless steel. The tube is approx. 1 in. across the major axis.

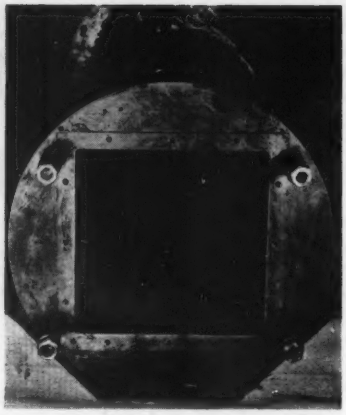

Fig. 3.—View of experimental cross-flow fuel channel.

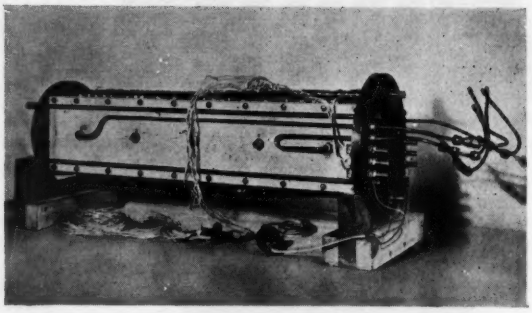

Fig. 4.—Test rig for examining heat transfer and pressure drop.

that for the lenticular tubes and the number per unit length adjusted to give the same oxide weight.

An in-line arrangement has been preferred to staggered pitching because of ease of assembly and also to minimize the possibility of vibration experienced in some conventional boiler installations using the staggered system. The effect is believed to be due to gas resonance in the "triangular" space between adjacent tubes in neighbouring banks. Although complete freedom from vibration at all Reynolds numbers cannot be assured until further experiments have been made the present evidence is that none will occur.

Element Design

Two elements have been designed for reactors with channel ratings of 760 kW* and 2.3 MW. The main parameters of these are shown in Table 1 and compared with the Kaiser-A.C.F. design[3]. The design of the individual elements is shown in Fig. 6. The capsules are formed from extruded 18/8 stainless steel lenticular tube with a 0.010 in. wall thickness and sealed by dished end-caps heliarc seam welded to the can. The tubes are packed with uranium oxide pellets of similar shape to the tube the end position being taken by porous magnesia insulation pieces. Stainless steel strips of 0.010 in. thickness are welded (edge-on) to the ends to form a ribbon defining the position of each can in a column. The columns are then inserted into the sleeve previously bored and broached to accommodate the appropriate number of rows. Steel retaining clips lock the columns into position. Individual elements fit together with the capsule rows aligned and this serves to maintain the flow pattern sufficiently constant for end effects to be apparent at only the inlet and outlet of a channel.

Cost of production of these assemblies is estimated to be similar to that of the present designs of rod clusters. For lowly rated reactors the weight of stainless steel involved may be greater than that required for rod clusters, but for ratings over (say) 50 MW/t the new design represents a saving. At very high ratings even the total number of welds necessary becomes smaller.

TABLE I—DESIGN PARAMETERS FOR THREE ADVANCED GAS-COOLED SYSTEMS

Parameter	Cross-Flow Design		GCPR
Channel output, MW	0.760	2.3	0.67
Channel rating, MW/t, UO_2	12.2	31.0	12.0
Capsule major axis, in.	1.2	0.8	—
Capsule minor axis, in.	0.3	0.2	—
Pellet o.d., in.	—	—	0.705
Pellet i.d., in.	—	—	0.323
Capsule o.d., in.	—	—	0.750
No. of capsules/row	6.0	8.0	—
No. of rods/cluster	—	—	7.0
Sleeve o.d., in.	6.0	6.0	4.25
Channel length, ft	13.5	10.0	14.5
Coolant inlet pressure, p.s.i.a.	285.0	400.0	405.0
Channel pressure drop, p.s.i.	4.5	25.0	16.0
Capsule longitudinal pitch, in.	2.45	1.01	—
Heated surface per channel, ft^2	28.0	52.0	19.0
Coolant inlet temp., °C	250.0	260.0	—
Coolant outlet temp., °C	538.0	538.0	538.0

*The AGR (*Nuclear Engineering*, Oct., 1958, p. 431) has an overall rating of 100 MW for 250 channels, a mean channel rating of 7.75 MW/t and a peak rating of 18.0 MW/t.

Further Development Avenues

The present specific shapes and sizes are not yet considered the optimum attainable with the cross-flow system; further experimentation is required and is under way. Also the comparative reactivity and other nuclear physics properties can only be roughly estimated. Calculations give results which are similar to the cluster arrangement but exponential experiments are required to justify this answer. In addition, the detailed requirements of any reactor system and the economic conditions governing its construction, particularly as regards enriched fuel prices and capital interest rates, are liable to lead to different optimization figures.

Parameters open to variation are as follow:—

Capsule cross-section. The dimensions of the axis of the capsule are set by the permissible temperature rise which in turn is governed by the reactor rating. A wide variation in the major/minor axis ratio is possible bearing

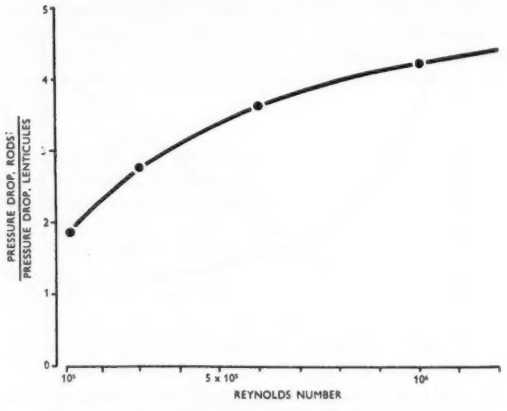

Fig. 5.—Ratio of pressure drop across smooth round capsules to that across smooth lenticular capsules (in-line configuration in cross-flow).

in mind the limitations imposed by pressure drop. The case of the circular tube has been discussed and the flat plate is equally unsatisfactory. For "thin" sections the curvature of both leading and trailing edges becomes critical and there appears to be a broad optimum ratio of between 2/1 and 3/1. The lenticular shape offers some strength advantages over a pure elliptical shape but this may not be a critical feature. Variations in heat transfer over the surface have to-date been measured only approximately and although more detailed tests will be made, present indications are that these are negligible.

Capsule length. Capsule length which quickly becomes dependent upon lattice pitch will probably be determined by engineering considerations modified by reactivity requirements. Charge/discharge requires a large lattice pitch and the implied large capsule length means cheaper manufacturing as well as fewer end caps and stringers. Lattice pitch of the AGR is 10¾ in. whilst in the G.E.C. ship design it is 11 in.

Surface Finish. As is proposed for the rod clusters, some surface roughening should increase heat transfer but this must be weighed against the disadvantages of increasing pressure drop, manufacturing cost and weight

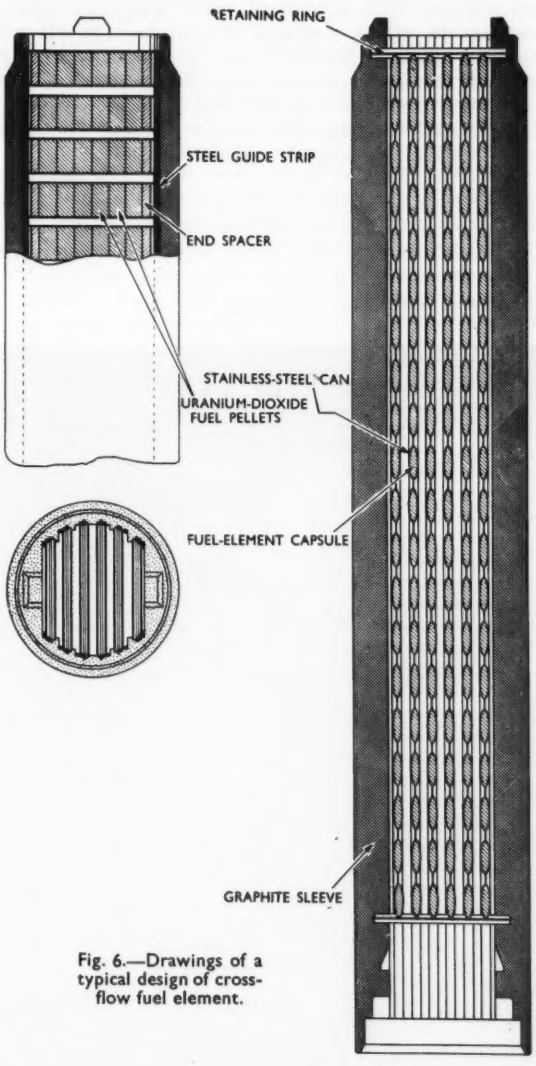

Fig. 6.—Drawings of a typical design of cross-flow fuel element.

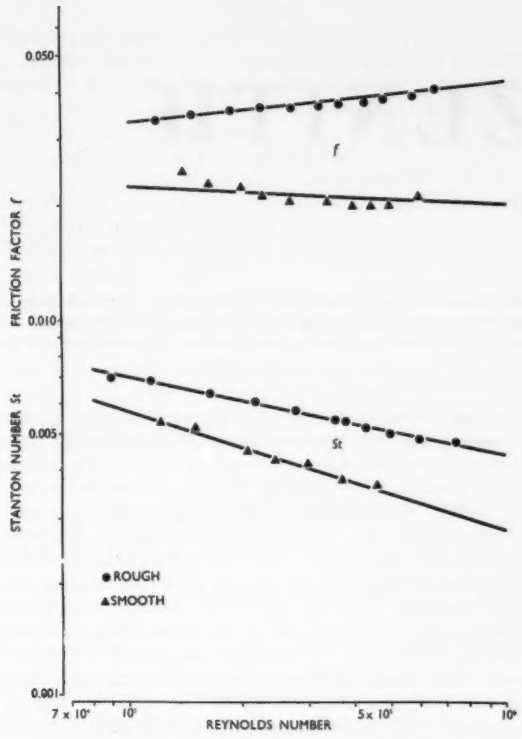

Fig. 7.—Typical heat transfer results for cross-flow fuel element with rough or smooth lenticular tubes.

of stainless steel. Experiments made with tubes including a bead on each of the leading edges indicate the expected improvement but the corresponding rise in pressure is high (see Fig. 7). In general it would appear, however, that roughening if adopted can give an overall gain.

Apparent Advantages of Cross Flow

At this stage of development direct comparison of the performance of cross flow and cluster type elements is difficult to make and not all the factors can be taken into account. The most striking advantage concerns the decreased pressure drop which is estimated to be half that experienced with cluster elements for channel outputs corresponding to a fuel rating of 10 MW/t. At higher ratings when the coolant pumping power assumes a progressively increasing proportion of the total output, decreases in pressure become correspondingly more important.

The application of cross flow elements need not be confined to the advanced gas-cooled reactor. It would seem similarly advantageous to use cross-flow annular finned Magnox elements in the present generation of base-load reactors but development of such an element would take a number of years and the heat transfer or pressure drop advantages are likely to be outweighed by the cost of introducing a "non-standard" and novel element into the mass production manufacturing and processing arenas at a late stage. But for future gas-cooled reactors the potentialities of the cross-flow system deserve intensive investigation.

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3. *A.C.F. Report*, ACF-GCPR-400.

ZENITH

By G. GUNNILL
and G. H. KINCHIN, M.A.
(*AEE, Winfrith*)

Main top insulation comprises a central plug and annulus containing Newtempheit and magnesium oxide.

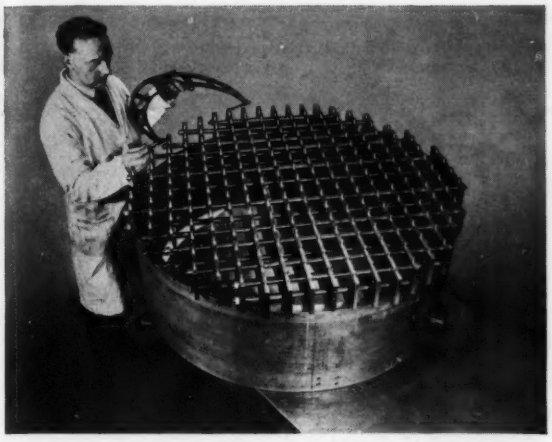
First reactor to go critical at the AEA's new establishment at Winfrith will be the zero energy high temperature facility, ZENITH, which will provide reactor physics information on nearly homogeneous high-temperature gas-cooled systems.

AS part of the U.K. AEA programme on high-temperature gas-cooled reactors, construction of a zero energy reactor, ZENITH, was proposed in 1956. The purpose of this reactor is to provide reactor physics information for nearly homogeneous high-temperature gas-cooled systems, and it will initially provide data for the design of a reactor experiment. The large temperature changes anticipated in this type of reactor give rise to large reactivity changes, and in order to obtain experimental verification of the magnitude of the temperature coefficients it will be possible to vary the core temperature of ZENITH over a wide range. High conversion ratios can be achieved with the U^{233}-thorium cycle in thermal reactors and as a preliminary step towards this cycle, a study of U^{235}-thorium systems is necessary.

A specification for ZENITH was prepared by the Authority and in 1957 a contract was awarded to The General Electric Company for the detailed design, construction and erection of the reactor. A brief description of the G.E.C. design was given at the 1958 Geneva Conference.[1]

The reactor comprises a central core of 235 fuel elements surrounded by a graphite reflector. The fuel elements are graphite cylinders, containing pellets of the fertile and fissile material interspaced with graphite, formed by screwing together short sections of tube. The lower end of the element sits in a conical ceramic bushing which in turn is carried on the fire bars. At the upper ends the elements turn into hexagons with the corners cut away for coolant passages; each element is held to its neighbour by graphite pegs. The Nimonic fire bars are carried on a support skirt system which transmits, through a second skirt, the load to the vessel wall. The reflector is supported by petal plates fixed between the central skirt and the brackets on the pressure vessel wall. The whole reactor rests on four columns, with rolling supports between

Looking into the core space. The graphite reflector is supported by petal plates.



Construction of the Nimonic firebars called for precision machining of a very high order. Tolerance on the 235 dowels which carry the ceramic bushings is 0.003 in. from the datum.

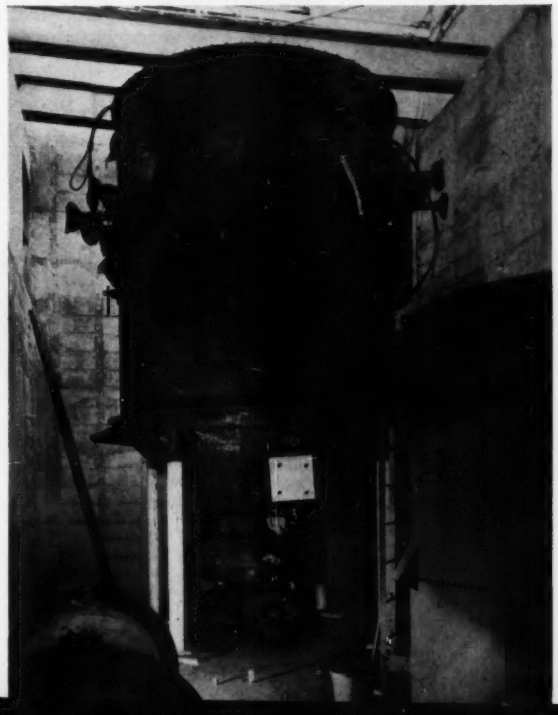
brackets and columns, dowel located, to allow significant thermal expansion.

ZENITH will operate at negligible power, the temperature being maintained by the circulating gas. Nitrogen, heated on entering the reactor, flows through the core into an upper mixing chamber where cool nitrogen is added before the downward flow through the reflector. The heating balance is maintained by an external heat exchanger.

Construction of the reactor started at Winfrith in September, 1958, and was completed in August, 1959. Since that time, commissioning tests have been proceeding.

Throughout the detailed design of a reactor there is a continuous process of balancing experimental requirements against engineering possibility. In dealing with the main components of the system separately, the interaction of changes in the design of one component on the design of another are obscured, but an attempt is made here to cover at least some of the alternative design possibilities which have arisen.

The main reactor vessel is supported on four columns.



Heating

The specification required that the temperatures within the reactor should be comparable to those of a power reactor of this type, with independent control of temperature in the core and reflector, in order that temperature coefficients may be separated.

The specification is given as follows:—

Core maximum mean temperature, 800°C.
Reflector mean temperature, 400°C.
Heating and cooling cycle, 48 hours each.
Maximum mean temperature differential between core and reflector, 400°C.
Temperatures from 25°C upwards within the designed range to be held to ±10°C for a period not exceeding 4 hours.

The first scheme considered was that of hot plate heating, where the core and reflector graphite were mounted on their respective hot plates, which were independently electrically heated. Designs involving the use of graphite

Fig. 1. (Right)—Core and reflector temperature curves.

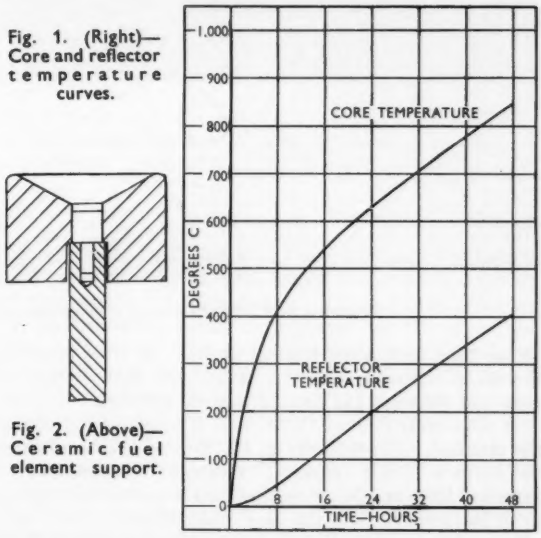


Fig. 2. (Above)—Ceramic fuel element support.

and of metal strip heaters were fully investigated. The disadvantages of this type of heating are:—

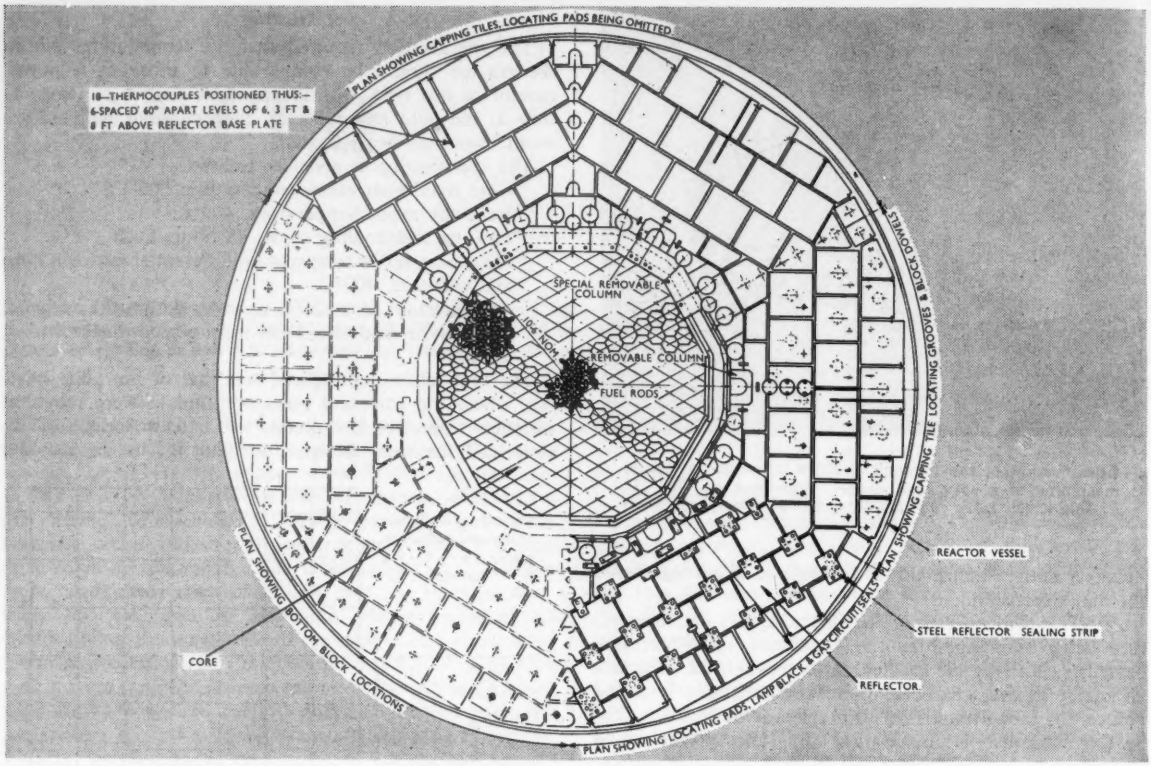
(a) Excessive temperature gradients in both core and reflector due to conduction heating from the base.

(b) Temperatures much in excess of 800°C must be attained in the core in order to achieve the temperature distribution required, followed by a relatively long relaxation period.

(c) Insufficient flexibility in the design to permit future changes in size of both core and reflector.

The scheme was therefore set aside in favour of gas heating.

Even with a hot plate scheme gas cooling employing a closed circuit is necessary. The closed circuit gas cooling of the reactor established in the hot plate scheme was developed to include a metal strip electrical heater at the base of the core. During the heating cycle the gas flows through the core and then downwards through the reflector. The heat input during this operation is 200 kW with a 3,000 lb/h mass flow of nitrogen through the core and reflector. A second by-pass gas feed to the plenum chamber above the reflector allows gas, at blower outlet temperature, to be mixed with the hotter gas leaving the top of the core. By this means the reflector temperature can be adjusted. Fig. 1 shows curves of temperature


18—THERMOCOUPLES POSITIONED THUS:—
6-SPACED 60° APART LEVELS OF 6, 3 FT &
8 FT ABOVE REFLECTOR BASE PLATE
PLAN SHOWING CAPPING TILES, LOCATING PADS BEING OMITTED
SPECIAL REMOVABLE COLUMN
REMOVABLE COLUMN
FUEL RODS
REACTOR VESSEL
STEEL REFLECTOR SEALING STRIP
REFLECTOR
CORE
PLAN SHOWING BOTTOM BLOCK LOCATIONS
PLAN SHOWING LOCATING PADS, LAMP BLACK & GAS CIRCUIT SEALS
PLAN SHOWING CAPPING TILE LOCATING GROOVES & BLOCK DOWELS

Plan view of ZENITH showing arrangement of reflector and its supporting and retaining structure.

versus time during the heating cycle. In view of circuit flexibility achieved with this design, the idea of separate core and reflector gas circuits was not pursued.

A total mass flow of 10,000 lb/h is available for cooling the graphite. The majority of this flow is directed through the by-pass to the reflector. Graphite temperatures are recorded from sets of chromel/alumel thermocouples placed at three levels in both the core and reflector. Also available to the operators is a recording of the mixed bulk gas temperature at the top of the reflector.

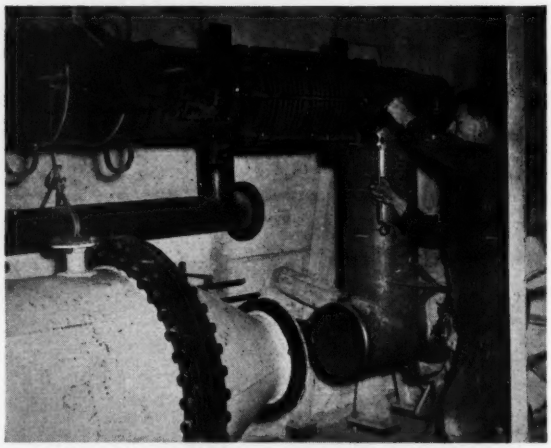
Four controllers maintain the required temperature conditions in the system. The first of these controls heater power by comparing a voltage from the core thermocouple with an adjustable demanded voltage, while the second controls the position of the core inlet valve to maintain the demanded mass flow through the core. The heater is safeguarded against burn-out by interlinking both controllers so that the maximum power which can be fed to the heater is related to the core gas flow. The third controller adjusts the valve in the reflector by-pass line to maintain the demanded reflector temperature; when the system is heating up, this valve is fully closed. The fourth controller adjusts the two valves in the heater exchanger line and the heat exchanger by-pass to give the required gas temperature at the main circulator. The flow of water through the heat exchanger is not varied.

Primary Circuit

The suggestion that helium be used as the heat transfer medium was rejected in view of the high cost of continuously replenishing a system of this kind, while CO_2 is unacceptable because of its reaction with graphite at 800°C. Nitrogen was chosen on the basis of compatibility and economy.

From previous experience within the Authority of producing gas-tight circuits of this type, a tolerable leak rate of 2 cu. ft/h was set, as it was attainable by reasonable control of the components during manufacture and did not demand special flange preparations and gaskets. The leak rate quoted is acceptable from the point of view of escape of activity from the circuit and of back-diffusion of oxygen. In addition to pressure testing each section of pipe and circuit component was also evacuated to a base pressure of 100 microns. Pipe jointing throughout the circuit utilizes corrugated iron rings. Silicone rubber O rings seal the top cover to the reactor vessel.

The specification for gas purity was determined by the



Coupling-up a bellows unit on the heat exchanger by-pass circuit.

maximum permissible rate of change of reactivity during an experimental period due to mass transfer of graphite from the reactor core. As a result of experimental evidence the bulk gas quality in the N_2 circuit was specified as follows:—

O_2	1 ppm
CO, CO_2, H_2O ..	each, 100 ppm
H_2	1,000 ppm

A by-pass purification plant handling 400 c.f.m. of gas is used and has three stages as shown in Fig. 2.

To clean the system before heating to elevated temperatures, the whole of the nitrogen circuit is evacuated to a base pressure of 25 mm Hg before filling with White Spot nitrogen. With the nitrogen purification plant in operation, the temperature of the system is raised. The oxygen content of the system is reduced by increasing the CO and CO_2 content; these gases are subsequently removed by the purifier. Initially, an enhanced rate of graphite loss by oxidation occurs, but this reduces to an acceptable value as the oxygen is extracted. Continuous indication of O_2, CO and CO_2 is provided from the gas analysis circuit, which utilizes a Hersch Cell for O_2 detection and an infra

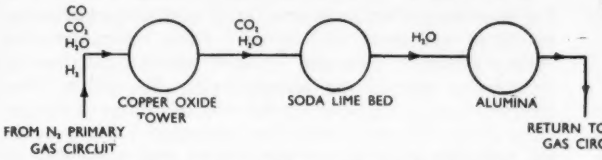


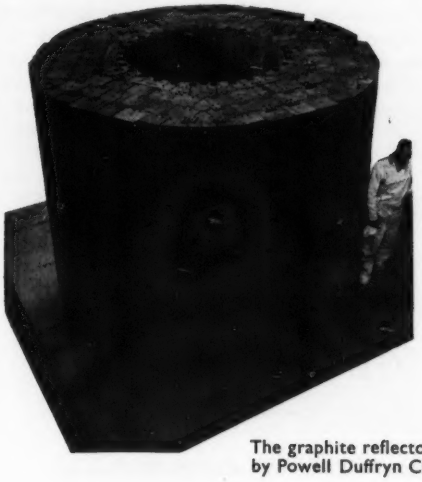
Fig. 3. (Left)—By-pass nitrogen purification plant. (Above) Top of the core showing positioning of the control rods and their drives.

red gas analyser for CO and CO_2. Warning is given if the O_2, CO and CO_2 content in the circuit rises above predetermined levels.

Materials of Construction

The reactor vessel and associated pipework and plant are of silicon-killed mild steel. Bellows units used for accommodating thermal expansion of the piping system are a welded fabrication of 1% chrome, 0.25% molybdenum. Supporting the reactor core there is a grillage fabricated from Nimonic 90 plate material.

Nimonic 75 tubing of 0.015 in. wall provides small diameter experimental holes within the core and reflector. Where this material is in intimate contact with the graphite at elevated temperatures (800°C) the formation of chrome carbide significantly reduces the life of such thin wall tubes. Investigation of suitable finishes—nickel and copper plating—is in progress and experimental results obtained to date appear favourable.



The graphite reflector was machined by Powell Duffryn Carbon Products.

All insulating materials have been kept outside the gas circuit in the interest of maintaining gas purity. Insulating materials within the reactor vessel are contained either in 17/7 stainless-steel boxes or adjacent to the heater, in Nimonic 75 boxes. The main top insulation is in the form of a central plug surrounded by an annulus. The centre plug contains Newtempheit with a small addition of magnesium oxide; the annulus, where conditions are less stringent, comprises a layer of Newtempheit backed up by magnesium oxide. The insulating barrier between the core and reflector is of carbon black—heat treated in order to reduce its thermal neutron cross-section—at the expense of some reduction of thermal conductivity.

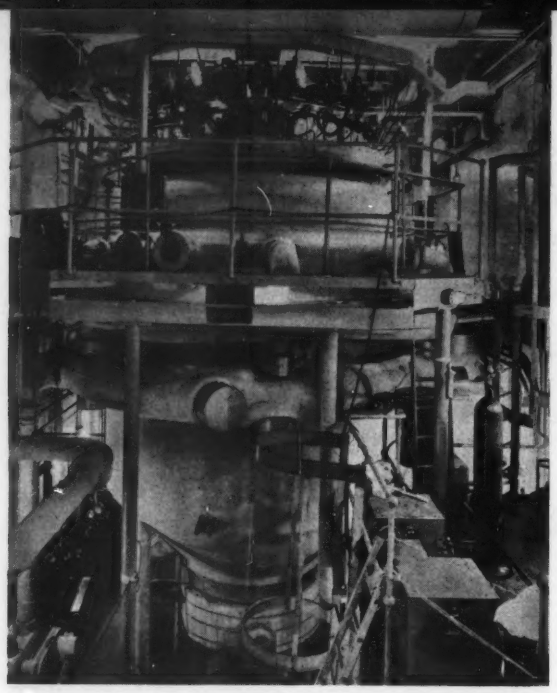
Ideally the ZENITH core should consist of a homogeneous mixture of uranium, thorium and graphite, with some flexibility in size and complete flexibility in composition. Flexibility in composition is achieved by subdividing the core into 235 fuel elements, each of which can be loaded with a mixture of fissile, fertile and graphite pellets. Composition is then varied by changing the numbers of pellets loaded into each fuel element.

The fuel elements are 8 ft long, 2.9 in. outside diameter and 1.133 in. inside diameter. The upper and lower ends of the fuel elements act as top and bottom reflectors, while the central region (between 4 and 5 feet long) is loaded with pellets the dimensions of which are shown in Table A.

TABLE A

Pellet	Diameter (inches)	Thickness (inches)
Fissile	1.1	0.067
Fertile	1.1	0.100
Graphite	1.1	0.067, 0.1, 0.2, 0.4, 0.8

The limit on the approach to homogeneity by reducing the size of pellets is a practical one, determined both by the time taken to load a large number of pellets and the robustness of the individual pellets.



Side view of the reactor showing (top) motorized control rod drives.

So far, nothing has been said of the materials of which the fissile and fertile pellets are made. These materials must be compatible with graphite at 800°C. Thorium oxide is acceptable as a fertile pellet material, but the degree of sub-division required for the highly enriched uranium pellets is such that undiluted uranium oxide would be too flimsy, and the first thoughts were to use magnesium oxide as a diluent. Experiments carried out by Chemistry Division at Harwell showed, however, that practically all of the gaseous fission products produced in such mixtures were released at 800°C. Even though ZENITH will operate at nuclear powers of less than 100 watts, such fission product release could cause great operational inconvenience, and the development by Metallurgy Division, Harwell, of a mixture of oxides which reduced fission product emission by a factor of 1,000 represented a major advance. The fuel pellets consist of 38% weight of uranium oxide in a matrix of alumina, magnesia, and silica.

Control

ZENITH uses reflector control, with absorbing rods in the reflector. Since the maximum reflector temperature is 400°C, as opposed to 800°C in the core, the engineering difficulties of designing a reliable control system are reduced. There are 30 control rod holes disposed in a ring round the core. Twenty of these holes will be occupied by motorized control rods and fixed absorbers may be loaded into the other 10 holes. The 20 motorized rods are made up of safety rods, shut-off rods, temperature rods, and coarse and a fine control rod. Except in the case of the coarse and fine rods, all of the mechanisms are identical and the duty of each rod can be selected from the control room. Rods are raised consecutively, rather than as a bank, and the rates are adjusted so that the maximum rate of addition of reactivity is 0.01% per second.

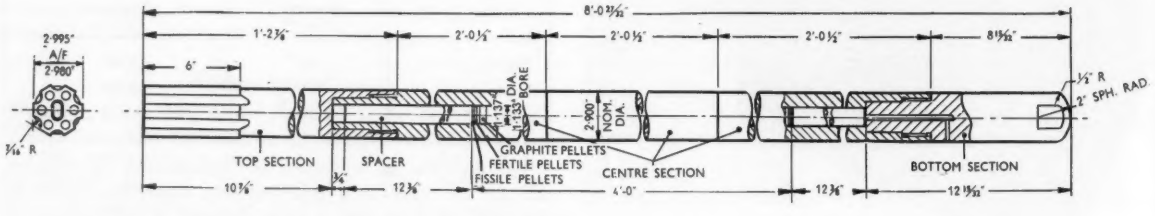
Each control rod is suspended by a cable which is winched on to a helical grooved drum and enclosed in a pressure-tight casing. The drive to the drum passes through a shaft seal and connects with the geared driving unit within the main gear case, which is not pressurized. A range of rod withdrawal speed over a distance of 78 in. can be varied between 1.5 and 32 minutes, by means of change gears using a motor speed of 2,750 r.p.m. Remote indication of rod position is by means of a Sperry slab-type synchro. All mechanisms embody a 24-volt d.c. electromagnetic clutch which releases the rods for free fall. The braking mechanism employs the flywheel-type energy absorber backed up with a mechanical end stop. This type of mechanism has been previously described as used on the ZEUS reactor at Harwell[2].

Instrumentation

In addition to the nucleonic instrumentation, the reactor has instruments which measure and control temperatures, pressures, gas flows, and so on. These instruments are mainly grouped on the two left-hand panels shown behind the control desk in the accompanying photograph. The temperature recorders, which show temperatures of various parts of the reactor circuit, viz. secondary cooling water, the ventilation air in the outlet duct and a number of temperature-sensitive measuring instruments, are on the extreme left. The mimic diagram on the next panel contains the controllers which regulate heater supply and gas flow as outlined previously. The third panel behind the control desk is the annunciator panel, common to the industrial and nucleonic instrumentation. Any fault, such as an excessive impurity content in the reactor circuit, causes a bell to sound, and the relevant warning sign is illuminated. The bell may be cancelled from the control desk, but the sign remains illuminated until the fault is corrected.

In addition to the indications and warnings described above there are a number of interlocks and trips. In the space available it is possible only to give examples such as the interlock, which prevents the heater from being operated with the gasholder empty, and the trip, which shuts off the power supply to the heater in the event of an earth fault.

There are six flux measuring chambers in ZENITH. The siting of these instruments has not been easy because there is insufficient experience of the reliability and lifetime of fission chambers at 800°C to warrant their use as reactor instruments. The outer regions of the reflector are screened by the control rods, so that the position finally chosen for the six instrument holes was at the inner edge of the reflector on a pitch radius less than that of the control rods. There will be some operational inconvenience



The ZENITH fuel element comprises pellets of U^{235} interspersed with thorium and graphite in a graphite sleeve.

because of the effects of nearby control rods on flux at the instrument positions.

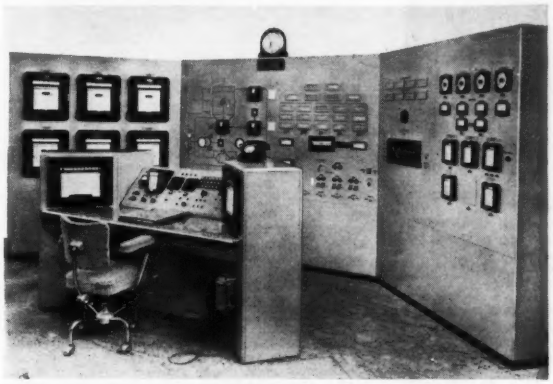
There are four pulse-counting fission chambers, two for use at low power and two at high power, and two current fission chambers feeding shut-down amplifiers. The pulse-counting chambers operate at reflector temperature, but the d.c. chambers are air-cooled to prevent spurious trips due to high leakage currents across the insulators. The shut-down amplifiers give automatic shut-down in the event of high flux, failure of H.T. supplies or a break in the connector between chamber and amplifier.

Neutron flux is displayed on the linear and logarithmic recorders at either end of the control desk. The high or low flux chamber is selected by the range change switch on the linear recorder, but there is an automatic changeover on the logarithmic recorder. The flux measuring channel from which the control desk indication of reactor period is derived is also automatically changed as power level increases. Direct indications of logarithmic flux and period from each of the four pulse-counting channels are also given on the extreme right-hand panel behind the control desk, so that the operator has full information in the event of a recorder or range-change failure.

Control rod positions are mainly shown on the control desk, although further detailed information is presented on one of the control panels. Flip-over indicators show whether the safety, shut-off and temperature rods are in, out, or in motion, while digital indicators give the precise positions of the coarse and fine rods. The safety and shut-off rods are automatically raised in sequence by turning the master switch to the appropriate positions. The temperature rods are selected by a switch on the control desk and are raised and lowered by push-buttons, as is the coarse control rod. The fine control rod is moved by a lever which controls the speed of movement by its deflection from the central position.

As in the heater control circuit, there are a number of trips and interlocks which shut the reactor down by releasing some or all of the magnetic clutches in the control rod mechanism, the most important being the period and high flux trips.

There are four installed gamma monitors, one by the control room, one in the bonnet and two at different levels in the pit. The pit monitors repeat their readings outside the two doors which provide access to the pit and the reading from two of the monitors can be selected for recording in the control room. A fast neutron monitor is also installed in the bonnet. Filters are provided in by-pass lines in the ventilation outlet duct so that fission product activity can be monitored.



The main control room for ZENITH was built by G.E.C.

Secondary Containment

The reactor pit and bonnet form a closed space penetrated only by three doors and the inlet and outlet ventilation ducts. The reasons for this containment are to cut off the air supply in the event of a rupture of the primary circuit which might lead to rapid oxidation of the core graphite; to confine the small quantities of activity escaping from the reactor which, although they would not present a health hazard, would interfere with counting experiments in the building, and to ensure the adequate distribution of incoming air so as to maintain reasonable working temperatures in the pit.

The walls and roof of the pit provide adequate shielding from radiation. The roof is of barytes concrete blocks 3 ft 6 in. thick which are mounted on support beams. In view of the use of the top of the biological shield as a continuation of the floor of the building the barytes blocks are reinforced to carry a super load of 200 lb/sq ft. This is the first time that reinforced barytes concrete beams have been employed as structural members. The end wall across the pit is constructed of Portland cement concrete blocks of 150 lb/cu ft density. The maximum internal design pressure of the biological shield is 8 in. W.G.

Trolley shielding doors allow entry through the roof for experimental equipment. Access to the bonnet is through airlock doors during reactor operation. Interlocks on the two doors leading to the pit prevent entry while the reactor is operating, although it is always possible to open the doors from the inside.

Filtered air is distributed through the pit from the inlet duct, while a separate supply of air is fed into the bonnet. All of the incoming air is extracted by two fans at the bottom of the pit having a total capacity of 6,000 c.f.m., so that the whole of the contained space is slightly below atmospheric pressure.

Reactor Building

A steel-framed sheeted type of construction, the reactor building has a pit 30 ft deep, 20 ft wide and 80 ft long. The reactor installation uses approximately half the length of the pit. An annexe on one side of the reactor hall houses the control room. The total electrical demand for the complete installation is approximately 500 kVA.

Reactor Physics Measurements

Few of the standard techniques for reactor physics measurements can be used in ZENITH. To give a simple example, normal methods for the determination of cadmium ratios are not possible at high temperatures because of the low melting point of cadmium. Nevertheless, it is possible to choose materials which can be used as foils for the determination of fine structure and macroscopic flux distributions and high temperature fission chambers have been developed for experimental purposes.

With ZENITH, emphasis will be placed on two features of particular interest in HTGC systems, neutron spectrum and temperature coefficients. It should be possible to make a direct measurement of neutron spectrum by chopping a beam of neutrons from the reactor while the complementary method of determining spectrum-sensitive cross sections will give most useful information.

Finally, in discussing the experimental work it is not possible to ignore reactor calculations. The aim of the experiments is to establish satisfactory methods of calculation for these systems and the closest collaboration between experiment and theory is essential.

REFERENCES

1. Mitchell, K. J., and Geary, R. A., "The high temperature zero energy reactor, ZENITH." Proc. 2nd Int. Conf., 1958, Vol. 10, P/1463. (Summary *Nuclear Engineering*, Oct., 1958, p. 428.)
2. The World's Reactors, No. 5—ZEUS. *Nuclear Engineering*, Sept., 1956, facing p. 234.

ZENITH—

Main and Sub-Contractors

Positioning shielding blocks (James Drewitt & Son).

Main Contractors to AEA

G.E.C. ATOMIC ENERGY DIVISION, Erith, Kent.
Detailed design and supply of ZENITH, the basic concept and overall design of the reactor and its fuel element were the work of the Authority who, throughout, have supervised the design and manufacture of the plant. The 200 kW heater in the main gas circuit was supplied by the electric furnace department of the Engineering Works at Erith.

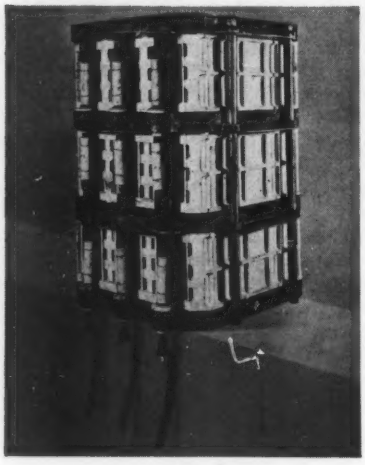
H. M. HOBSON, LTD., Hobson Works, Fordhouses, Wolverhampton, Staffs.
Design of gearboxes and control rods. Manufacture of gearboxes.

Sub-Contractors

AITON AND CO., Derby.
Expansion bellows (gas circuit). Steel tubes (butterfly valves). Special tubes (valve positioner guides). The gas ducts are fabricated from carbon steel tube and comprise 12-in. bore inlet and return circuits between the blower and reactor vessel with connections to the filter and cooler.

ALEXANDER CONTROLS, LTD., Reddicap Hill, Sutton Coldfield, Warwickshire.
Alcon and solenoid valves (gas circuit).

ACCLES AND POLLOCK, LTD., Oldbury, Birmingham.
Nimonic tubes 0.10-in. thick, made for Talbot Stead for building up into instrument thimble assemblies. Composite tubing mild steel/mild steel, both tubes being 18 g., supplied to Heat Exchangers. These were built into heat exchangers. The purpose of using composite tubing was to provide a gas leak path in case of fracture of one of the tubes. S.S. tubing for insulating boxes.



G.E.C. 200 kW electric heater.

BRITISH INDUSTRIAL GASES, LTD., 700 Cambridge Road, Enfield, Middx.
Regulating valves (gas circuit). Equipment for nitrogen bottling and filling.

BRENTFORD TRANSFORMERS, LTD., Manor Royal, Crawley, Sussex.
Voltage regulation transformers.

BAILEY METERS AND CONTROLS, LTD., Purley Way, Croydon, Surrey.
Tatcho indicator (generator receiver).

BURGESS PRODUCTS, LTD., Brookfield Road, Hinckley, Leics.
Micro switches (fuel element flask).

BARNABY ENGINEERING CO. (1950), LTD., Bourne Road, Bexley, Kent.
Thermocouple housings (mixed gas measurement). Solenoid locks (containment dome). Gauges (insulation box).

BRITISH ROTOTHERM CO., LTD., Merton Abbey, London, S.W.19.
Thermometers (ventilation system).

BUDENBURGH GAUGE CO., LTD., Broadheath, near Altrincham, Ches.
Pressure indicator (vacuum pump).

BLACK AUTOMATIC CONTROLS, LTD., Leafield, Corsham, Wilts.
Solenoid valves and flow switches (reactor services).

BROOKES AND WALKER, LTD., 47 Great Eastern Street, London, E.C.2.
Plug cocks (instrument services).

BRITISH INSULATED CALLENDER'S CABLES, LTD., 21 Bloomsbury Street, London, W.C.1.
Special mineral insulated thermocouples and high-temperature mineral insulated heating cables (nitrogen purification plant).

CRANE, LTD., 15 Red Lion Court, London, E.C.4.
Valves (water circuit).

RICHARD CRITTALL MARINE, LTD., 151 Great Portland Street, London, W.1.
Deflector grilles (ventilation services).

COLUMBIAN GENERAL BLACKS, LTD., Four Ashes, Wolverhampton.
Lamp blacks (thermal insulation).

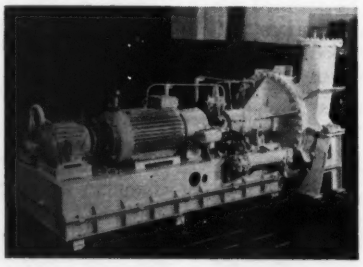
CHAMBERLAIN AND HOOKHAM, LTD., Solar Works, New Bartholomew Street, Birmingham, 5.
Transformers (voltage regulation unit).

THOS. CLARKE AND CO., LTD., Albert Road, Bristol, 2.
All electrical installations.

ROBERT INGHAM CLARK AND CO., LTD., 93 New Cavendish Street, London, W.1.
Rubber paint chromate (general painting).

CAPE ASBESTOS CO., LTD., 114 and 116 Park Street, London, W.1.
Asbestos lagging discs (nitrogen purification plant).

CLYDE RUBBER WORKS, CO., LTD., Renfrew.
Rubber sleeves (ventilation ducting).



Nitrogen circulator (Davidson & Co.).

DAVIDSON AND CO., LTD., Sirocco Engineering Works, Belfast, N. Ireland.
High-temperature nitrogen circulator of high aerodynamic efficiency; 11 : 1 speed range; air-lubricated shaft seal; gas-tight casing (reactor vault).

DELTA TECHNICAL SERVICES, LTD., Fairfield Road, Kingston-on-Thames, Surrey.
Flow and pressure switches (reactor services).

JAMES DREWITT AND SON, LTD., Ringwood Road, West Howe, Bournemouth.
Erection of concrete blocks for bulkhead wall and shield roof. Painting of plant and pit walls of reactor.

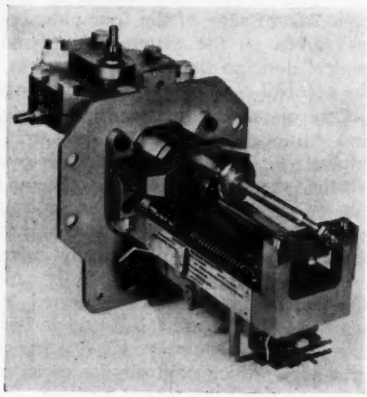
DOWTY NUCLEONICS, LTD., Brockhampton Park, Andoversford, Glos.
Switch units (reactor services).

EVERSHED AND VIGNOLES, LTD., Acton Lane Works, Chiswick, London.
Automatic flow control of nitrogen by Evershed electronic repeater system. Regulation of temperature of electric heater by Mk. 4 controller.

EDWARDS HIGH VACUUM, LTD., Manor Royal, Crawley, Sussex.
Valves and valve adaptors (reactor services). Speedivac rotary pumps for evacuating insulation boxes.

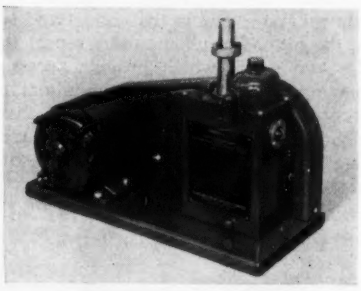
ENGLISH STEEL CORPORATION, LTD., North Steel Works, Openshaw, Manchester.
Steel plates for skirt support ring.

ESSO PETROLEUM CO., LTD., 36 Queen Anne's Gate, London, S.W.1.
Hydraulic fluid (electro-hydraulic valve positioners).



Evershed differential pressure transmitter.

ELECTRONIC MACHINE CO., LTD., Mayday Road, Thornton Heath, Surrey.
U-tube assembly between insulation boxes and reactor circuit. The "U" tube contains butyl phthalate, and the original level is such that if there is more than 3½ lb/sq in. pressure difference between the two sides of the assembly the liquid will spill over into one or other of the conical containers. Return from the container to the "U" tube, after restoration of equal pressures, is made by a small-bore drain through a restriction nozzle.



Speedivac vacuum pump (Edwards).

FIBREGLASS, LTD., Ravenhead, St. Helens, Lancs.
Air inlet filter (reactor pit ventilation).

FIRTH VICKERS STAINLESS STEEL, LTD., P.O. Box 131, Staybrite Works, Weedon Street, Sheffield 9.
Nimonic skirt (core support assembly).

FELCO HOISTS LTD., 29 Cromwell Road, S. Kensington, London, S.W.7.
Travelling chain block (reactor area).

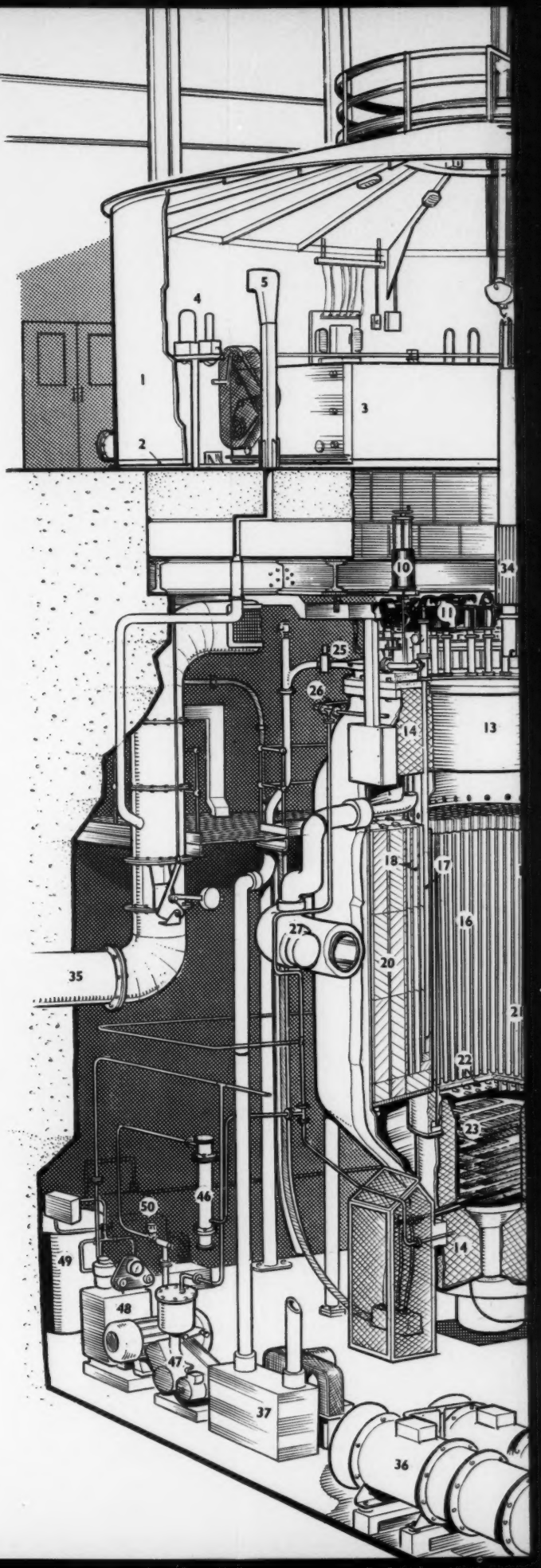
HALL ENGINEERING LTD., Shrewsbury, Salop.
Airlock with two airtight doors (containment dome). Two crane-hinge airtight doors and one

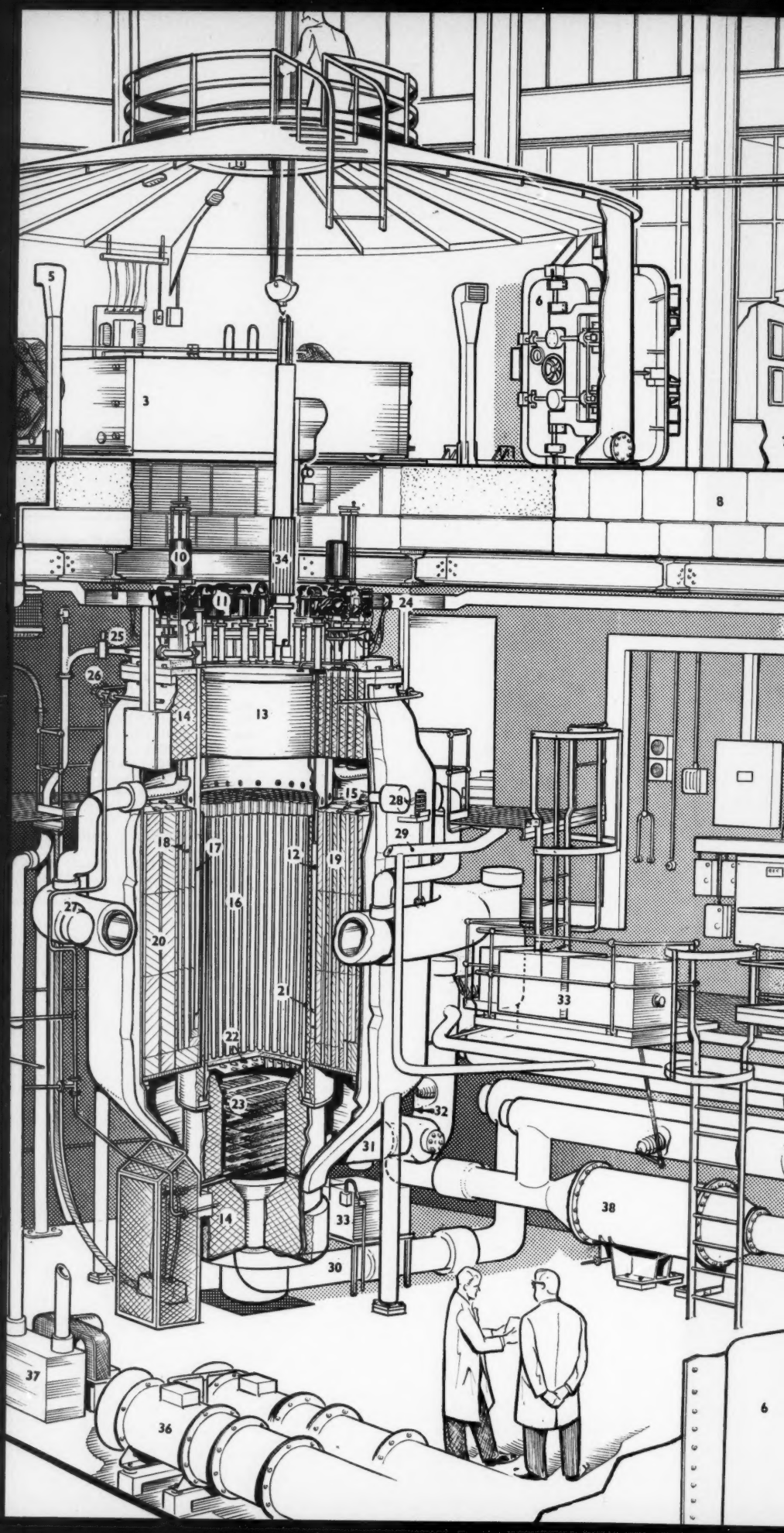
The World's Reactors

No. 23 ZENITH

KEY

1. Gastight bonnet
2. Gastight seal
3. Trolley shielding doors
4. Health monitors
5. Bonnet ventilation ducts
6. Air-lock
7. Control room
8. Top shielding
9. Support beams
10. Head amplifiers
11. Control rod motors
12. Control rods
13. Central cover
14. Insulation boxes
15. Gas mixing zone
16. Fuel elements
17. Flux measuring chamber
18. Flux scanning holes
19. Experimental holes
20. Graphite reflector
21. Thermal insulator
22. Core support structure
23. Heater
24. Cable duct
25. Thimble cooling main
26. Vacuum ring main from insulation boxes
27. Inlet ring main to reflector plenum
28. Thermocouple gland plate
29. Outlet from aspirating thermocouples
30. Inlet main to heater
31. Outlet from reactor vessel
32. Gas filter
33. Valve control units
34. Fuel element charging machine
35. Ventilation inlet
36. Ventilation outlet
37. Thimble cooling circulator
38. Heat exchanger
39. Gas circulator
40. Circulator drive
41. Gas holder
42. CuO towers
43. Sofnolite towers
44. Alumina towers
45. Gas analysis recorders
46. Filter
47. Vacuum pump assembly
48. Gas compressor
49. Gas receiver
50. Vacuum pump for reactor circuit

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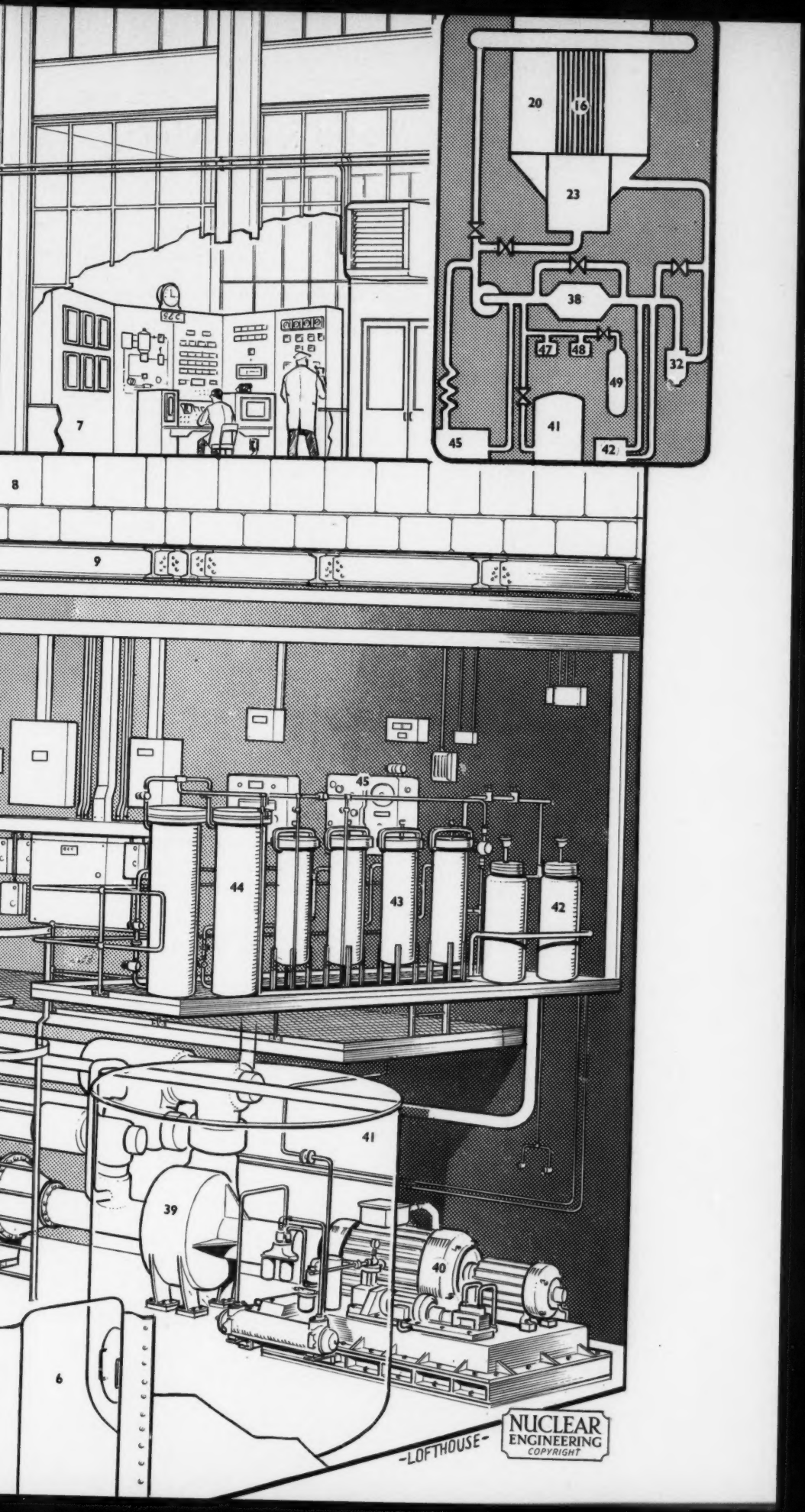
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-LOFTHOUSE-
NUCLEAR
ENGINEERING
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No.

TYPE:

PURPOSE:

LOCATION:

OPERATION:

RATING:

FUEL:

CORE:

LATTICE:

REFLECTOR:

CIRCULATING GAS:

CIRCULATOR:

VESSEL:

CONTROL RODS

FLUX:

HEAT EXCHANG

WATER COOLER

PRIMING SOURC

SHIELDING:

CONTAINMENT:

The World's Reactors

No. 23 ZENITH—Zero Energy High Temperature

Thermal heterogeneous.

SE: High temperature physics experiments on gas-cooled reactors.

TION: Atomic Energy Establishment, Winfrith, Dorset.

ATION: Autumn, 1959.

G: 100 W, max.

Uranium oxide, 38 wt.% in matrix of alumina, magnesia and silica.
Elements: UO_2/ThO_2 pellets in graphite tube.
No. of elements: 235.
Tube dimensions: overall 8 ft × 2.9 in. o.d., 1.133 in. i.d.
Fuelled length: 5 ft.
Pellet diameter: 1.1 in.

Overall size: 4 ft dia. × 4 ft high.
Max. core temperature 800°C.

CE: Gas flow area: 15%.
Pitch: 3 in. triangular.

CTOR: Graphite.
Dimensions: 10 ft 6 in. nom. dia. × 8 ft high.
Max. reflector temperature 400°C.
Gas flow area 5%.

LATING Nitrogen.
Inlet temperature: 400°C.
Outlet temperature from heater: 950°C.
Flow: 10,000 lb/h.
Heating system: electric.
Power consumption: 200 kW.

LATOR: Variable speed, centrifugal blower.
Max. speed: 2,990 r.p.m.
Max. power: 30 h.p.

: Dimensions: 20 ft 5⅜ in. overall × 10 ft 7½ in. i.d. × ¾ in.
Material: silicon killed m.s.
Max. temperature: 450°C.
Design pressure: 14.7 p.s.i., externally applied.
Flat top thickness: 3⅛ in.

ROL RODS: Number: 20 motorized, 10 static.
Material: B_4C tamped in hollow m.s. tube.
Annular width: 0.243 in.
Length: 5 ft.
Rod speeds: 1.5 to 32 min for complete withdrawal.
Max. reactivity rate: 0.01%/sec.

Central core: 10^8n/cm², sec.

EXCHANGER: Shell-tube, 10 ft 8 in. long.
Tubes: 532, bimetal m.s.
Tube size: ¾ in. o.d. × 18 g × 18 g.
Water flow: 3,000 lb/h.

R COOLER: Air cooled.
Air flow: 40,000 ft³/min.

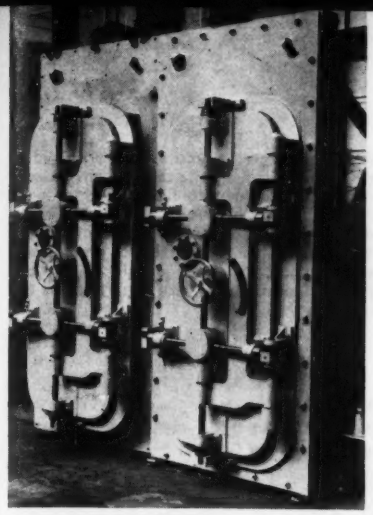
G SOURCE: Type: Ra-Be.
Neutron strength: 5×10^6n/sec.

ING: Thermal shield: 2 in. lamp black.
Biological shield: concrete.

AINMENT: Concrete vault covered with steel bonnet.
Bonnet: 28 ft i.d. × 12 ft 8 in. high, 3/16 in. thick.
Design pressure: 8 in. w.g. internal, 2½ in. w.g. external.
Material: B.S.S. 15 Grade 1.

Data sheets in this series already published in " Nuclear Engineering " are:

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. RUSSIAN 5 MW (November, 1956)
No. 8. DIDO (January, 1957)
No. 9. THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION (February, 1957)
No. 10. BERKELEY POWER STATION (March, 1957)
No. 11. BRADWELL POWER STATION (April, 1957)
No. 12. DOUNREAY FAST REACTOR (June, 1957)
No. 13. EBWR (July, 1957)
No. 14. RWE 1 (September, 1957)
No. 15. LIDO (November, 1957)
No. 16. PLUTO (April, 1958)
No. 17. MERLIN (May, 1958)
No. 18. GI (June, 1958)
No. 19. HINKLEY POINT POWER STATION (July, 1958)
No. 20. NRU (February, 1959)
No. 21. HALDEN (March, 1959)
No. 22. LATINA (October, 1959)



Crane-hinge airtight doors (Hall Engineering).

fire-resisting door in biological shield. Gas-sealing strips and aluminium tubes (reflector). Blanking plates (control and plant rooms).

HAMWORTHY ENGINEERING LTD., Fleets Corner, Poole, Dorset.
03M nitrogen compressor, 10 c.f.m. free gas delivery at 2,500 p.s.i. Aurora L5 turbine pump, 20 g.p.m. at 87 p.s.i. (gas bottling).

G. A. HARVEY AND CO. (LONDON), LTD., Woolwich Road, Charlton, London, S.E.7.
Ventilation ducts and equipment.

HEAT EXCHANGERS LTD., 1 Wardour Street, London, W.1.
Nitrogen/water heat exchangers.

HONEYWELL CONTROLS LTD., Ruislip Road East, Greenford, Middx.
Flux recorder indicators.

IGRANIC ELECTRONIC CO. LTD., Elstow Road, Bedford.
Push buttons, solenoids and contact blocks for control panels.

ALFRED IMHOF LTD., Ashley Works, Cowley Mill Road, Uxbridge, Middx.
Instrument rack (control rods).

IMPERIAL CHEMICAL INDUSTRIES LTD., Imperial Chemical House, Millbank, London, S.W.1.
Trichlorethylene for de-greasing.

ISOPAD LTD., Barnet By-pass, Boreham Wood, Herts.
Isojacket electric surface heater for nitrogen purification plant.

RICHARD KLINGER LTD., Klingerit Works, Sidcup, Kent.
Valves, O rings and cocks for reactor services.

LONDEX, LTD., 207 Anerley Road, London, S.E.20.
Process timing unit.

Isomantle electric surface heater.

LONDON NAMEPLATE MFG. CO., LTD., Zylo Works, Brighton, 7.
Nameplates for valves.

ROBERT MACLAREN AND CO., LTD., Eglington Works, Kilbirnie Street, Glasgow.
Thermostats.

MATTERSONS, LTD., P.O. Box 31, Healey Works, Rochdale.
Electric hoist block and chain (over reactor).

METROPOLITAN VICKERS ELECTRICAL CO., LTD., Trafford Park, Manchester, 17.
Filtometer-resistance indicator for ventilation circuit.

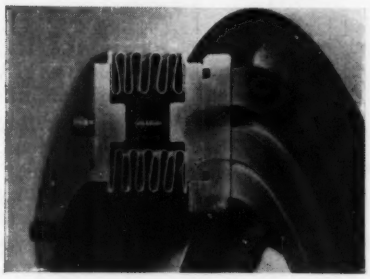
MUIRHEAD AND CO., LTD., Beckenham, Kent.
Stud switches for thermocouples.

D. NAPIER AND SONS, LTD., 211 The Vale, Acton, London, W.3.
Gas-lubricated seal for nitrogen blower.

NEGRETTI AND ZAMBRA, LTD., 122 Regent Street, London, W.1.
Pressure switches (reactor services).

NEWALLS INSULATION CO., LTD., Washington, Co. Durham.
Thermal insulation for reactor vessel and gas circuits.

NEWMAN HENDER AND CO., LTD., Woodchester, Stroud, Glos.
Bronze valves (thimble cooling plant).



Sectioned Napier gas-lubricated seal.

PARKHALL POTTERY CO., LTD., Sutherland Road, Longton, Stoke-on-Trent.
Capping tiles and fuel element support (reactor core). Mainly zirconium, steatite alumina, remainder ceramic. Ball clay as a plasticizer.

POWELL DUFFRYN CARBON PRODUCTS, LTD., Springfield Road, Hayes, Middx.
Machining and erection of graphite core. Bursting disc assemblies in graphite.

POWER FLEXIBLE TUBING CO., LTD., Derby Works, Vale Road, London, N.4.
Bellows units for ventilation tube connection.

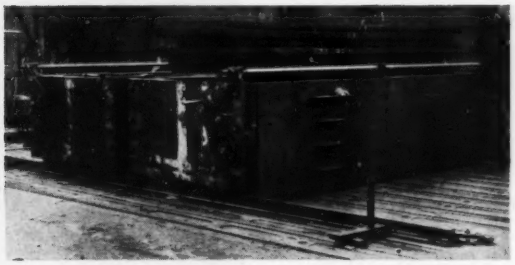
PYROTENAX, LTD., Hedgeley Road, Hebburn, Co. Durham.
Thermocouples.

RAWLPLUG CO., LTD., Cromwell Road, London, S.W.1.
Cement-in sockets for anchoring cable racking in perimeter ducting. Rawloops. Rawlties and Rawlbolts for general construction.

RECORD ELECTRICAL CO., LTD., Broadheath, Altrincham, Ches.
Flux deviation health recorders and indicators for main control panels.

REDHEUGH IRON AND STEEL CO. (1936), LTD., Team Valley, Gateshead, Co. Durham.
Pit gallery steelwork, containment dome, support assemblies, secondary circuit platform and pipe upports.

EDHEUGH-WILLEY, LTD., Water Lane, Exeter, Devon.
Erection of containment dome above reactor vessel together with supports for the amplifier head and junction box, and secondary circuit platforms.



Rothwell shield trolley (with proof load).

REDPATH BROWN AND CO., LTD., 3 Duncannon Street, London, W.C.2.
Biological shield roof and cover and bulkhead wall supporting structures.

RELIANCE TELEPHONE CO., LTD., 163 Newhall Street, Birmingham, 3.
Telephone systems and telecommunication systems.

RHEOSTATIC CO., LTD., Farnham Road, Slough Bucks.
Thermostats for control circuit.

ROTAMETER MANUFACTURING CO., LTD., 330 Purley Way, Croydon, Surrey.
Rotameters for (a) gas flow measurement; (b) flow alarms and metering.

J. T. ROTHWELL AND CO., LTD., Canal Boiler Works, Church, Lancs.
Shield trolley (reactor pit). Support racks (fuel elements). Support platform (control rod mechanisms). Cooler assembly vessels (nitrogen purification plant). Heater trolley and lifting beams (lifting heater into reactor).

SAUNDERS VALVE CO., LTD., Grange Road, Cwmbran, Mon.
Valves for reactor services.

SERCK RADIATORS, LTD., Warwick Road, Birmingham, 11.
Heat exchanger for gas compressor.

SYDNEY SMITH AND CO. (NOTTINGHAM), LTD., Basford Works, Egypt Road, Nottingham.
Needle valves for reactor services.

SPEEDY AND EYNON, LTD., Warstone Lane, Birmingham, 18.
Grid assembly for core support.

STURTEVANT ENGINEERING CO., LTD., Southern House, Cannon Street, London, E.C.4.
Filter for insulation box. Filter plant for nitrogen by-pass circuit.

TALBOT STEAD TUBE CO., LTD., Green Lane, Walsall, Staffs.
Thimbles (flux scanning). Reactor cans (fuel element flask). Various stainless steel tubes.

TEDDINGTON INDUSTRIAL EQPT., LTD., Windmill Road, Sunbury-on-Thames, Middx.
Shut-off and bellows gland valves for reactor services.

TELEFLEX PRODUCTS, LTD., Basildon, Essex.
Remote control system for isolating dampers.

THERMOCOUPLE INSTALLATIONS, LTD., 2-10 Valentine's Place, Blackfriars Road, London, S.E.1.
Step controller for bonnet heating equipment.

TRENT VALVE CO., LTD., 47 Great Eastern Street, London, E.C.2.
Needle valves for reactor services.

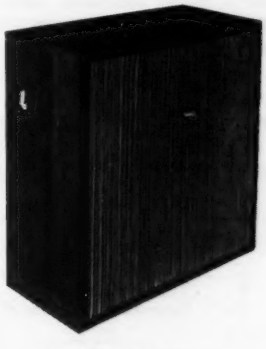
UNIVERSAL EQPT. (NORTHOLT), LTD., Belvue Works, Green Lane, Hounslow, Middx.
Instrument cover plates for fuel element store.

VANDYKE ENGINEERING, LTD., Eastern Industrial Estate, Harlow, Essex.
Lamp black seals for reactor core. Hoist equipment and shielding beam (flux scanning). Insulation boxes (reactor vessel).

VOKES, LTD., Henley Park, Guildford, Surrey.
Six 44/5 Absolute filters in a bank 3 x 2 formation for reactor pit ventilation.

JAMES WALKER AND CO., LTD., Lion Works, Woking, Surrey.
Lioncelle strip for containment dome gaskets and blanking plate seals.

HENRY WIGGIN AND CO., LTD., Wiggin Street, Birmingham, 16.
Nimonic plate for insulation boxes and core support plates.



Vokes 44/5 filter.

WOOD BROS. AND CO. (GASKETS), LTD., Dewsbury Road, Cleckheaton, Yorks.
Armco iron gaskets for pipework services.

WOODS OF COLCHESTER, LTD., Colchester, Essex.
Aerofoil units for pit ventilation.

WORTHINGTON SIMPSON, LTD., Lowfield Works, P.O. Box 17, Newark, Notts.
Monobloc pump (cooling water services).

WRIGHTS FORGE AND ENGINEERING CO., LTD., Sedgeley Road West, Tipton, Staffs.
Fabrication of reactor vessel.

Gas-side Heat Transfer Investigations

In the design of a nuclear boiler, greater accuracy is required in calculating heat exchange surface than in the case of conventional industrial heat transfer plant. In order to facilitate this, more information is needed on the friction factors for flow across banks of extended surface tubes, as well as on the influence of various parameters such as tube size and pitching on boiler dimensions. Experimental heat transfer facilities specially developed for the purpose and test results obtained on them are described by the authors.

By D. A. BARNARD, B.Sc., N. CHERRETT, M.Sc. and G. D. ROBINSON, B.Sc.
(Head, Wrightson and Co., Ltd.)

THE majority of present-day industrial heat transfer problems offer little difficulty to the engineer because of the mass of fairly accurate published data on thermal performance. In most heat transfer calculations the surface area is suitably weighted to allow for experimental inaccuracies and for uncertain scale and dirt factors, without adding appreciably to the total capital or running costs of the whole plant. In the case of a nuclear power boiler of high capital cost the position is different, for if a large "factor of safety" is used the increase in first cost will be great. At the same time it may be noted that under the "clean" conditions existing dirt factors are negligible. There is, therefore, little margin for error when calculating the area of heat exchange surface in a nuclear power boiler.

In the present-day type of gas-cooled graphite-moderated nuclear power station, the gas film is the controlling resistance to heat transfer in the boiler and extended surfaces are used to reduce this as much as possible. At the time of the "Bradwell" inquiry there was some design data available for the calculation of gas-side heat transfer coefficients to extended surface tubes but very little information relating to friction factors for flow across banks of these tubes could be found. It was therefore imperative to obtain more accurate data, and also to examine the influence of various parameters such as tube size and pitching on boiler dimensions. For these reasons facilities were set up by Head, Wrightson and Co., Ltd., in their Central Research Laboratories, for the testing of different finned tubes and tube arrangements enabling gas-side heat transfer coefficients and pressure drops to be determined at different pressures and temperatures.

Description of Heat Transfer Facilities

In the present heat transfer laboratory there is a pressurized high temperature rig and an atmospheric pressure sorting rig. These evolved quite naturally from humble beginnings as a result of increasing experience and changing requirements.

Preliminary tests were carried out on a pressurized gas loop with steam condensing inside the finned tubes (see Fig. 1). In use, cold gas was passed over the tubes, the heat flow thus being in the reverse direction to that in an actual boiler. Several different tube arrangements were tested in this way. The test vessel (and direction of gas flow) was vertical, and pressure tapping lines were disposed so as to minimize buoyancy effects so far as possible.

This rig was later extended to include a heater for the gas. Cooling water was arranged to flow in two parallel paths through the tubes, so that heat flow was then in the correct direction.

The tests carried out on these two rigs were at gas temperatures up to 300°F and pressures up to 150 p.s.i.g. Although it was considered likely that dimensionless correlations obtained at low gas temperatures would be valid for high gas temperatures, it was thought that a programme of tests at a high temperature would resolve all doubts on the part of the client. Therefore, the next development was the installation of a new rig with more flexibility and the ability to reproduce more closely the operating condition of the boiler. This resulted in the present pressurized, high temperature rig which can operate at a gas pressure of 150 p.s.i.g. and temperature of 550°F (see Figs. 2 and 3). The gas is circulated by a specially stiffened centrifugal blower (normally intended for low pressure work) which is contained within a pressure vessel and driven from outside through a water-cooled mechanical seal. Heating is effected by an oil-fired furnace. Results from this rig at a mean gas temperature of 490°F and pressures of up to 150 p.s.i.g. have confirmed previous "low temperature" (220°F) results. It is therefore not the practice to test new tube matrices at "high temperatures" unless this appears

List of Symbols

C : Specific heat, B.t.u./lb, °F
d : Tube bore, ft
D_b : Equivalent diameter of a bank of finned tubes (Jameson)
$$= \frac{D_t}{\left[\left(\frac{H}{2\sigma}\right)^{0.4}\left(\frac{1}{2}\sqrt{\frac{D_t}{X-D_t}}+\frac{1}{2}\sqrt{\frac{D_t}{Y-D_t}}\right)\right]^4} \text{ ft}$$
D_t : Equivalent diameter of a finned tube (Jameson) $=2P/\pi Q$, ft
D_v : Volumetric equivalent diameter $=(4\times\text{nett free volume})/(\text{Wetted surface area})$, ft
G : Maximum mass flow rate of gas over finned tube matrix, lb/h, ft²
H : Height of fin, ft
h_o : Gas-side heat transfer coefficient referred to inside area, B.t.u./h, ft², °F
h : Gas-side heat transfer coefficient, B.t.u./h, ft², °F
h_w : Coolant-side heat transfer coefficient, B.t.u./h, ft², °F
h_{wall} : Tube wall heat transfer coefficient, B.t.u./h, ft², °F
k : Thermal conductivity, B.t.u./h, ft, °F
Nu : Nusselt number
P : Surface area of finned tube/foot length, ft²/ft
Pr : Prandtl number
Q : Length of projected perimeter of a finned tube on a diameter cross-section, ft/ft
Re : Reynolds number
v : Coolant velocity, ft/sec
X : Transverse pitch of tubes in cross-flow matrix, ft
Y : Diagonal pitch of tubes in cross-flow matrix, ft
ρ : Density, lb/ft²
σ : Space between fins in transverse finned tube, ft
μ : Viscosity, lb/ft, h

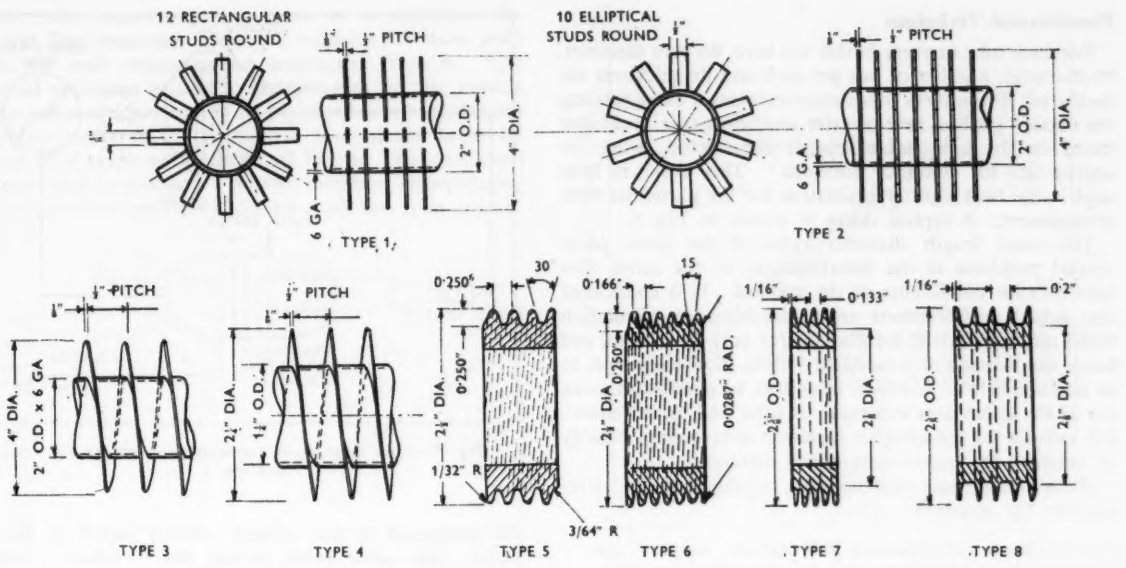


Fig. 1.—Types of extended surface tube, tested on the original rig.

for some other reason. The test vessels are now horizontal—eliminating any doubts as to the effects of buoyancy on pressure drop and making mechanical work on the test section much easier. For "high temperature" work an "Aroclor" type of organic heat transfer medium is circulated within the finned tubes, and the heat transferred is ultimately rejected to water in a separate exchanger; the transport properties of the Aroclor have been separately investigated. For "low temperature" work water is circulated directly within the finned tubes.

The running costs of such a large piece of equipment are high, and it rapidly became clear that some sort of subsidiary equipment was needed to evaluate the comparative merits of different tubes or tube arrangements, without necessarily providing accurate design data. Therefore, an atmospheric pressure "sorting rig" using low temperature (250°F) air was installed in the laboratory (see Figs. 4 and 5). Air is circulated in a closed circuit by means of a blower, over a steam heater and the matrix of tubes under test. This rig employs high air velocities in order to obtain Reynolds Numbers comparable with those in the boiler. These high velocities result in loud aerodynamic noises with most tube arrangements. The onset of noise is abrupt, at a mass velocity which varies with the particular matrix under test, and both heat transfer and pressure drop measurements are affected by it. Hence, in the opinion of the authors, it is unwise to use results from this rig for absolute design purposes (at least when operating within the noise range, as is usually necessary).

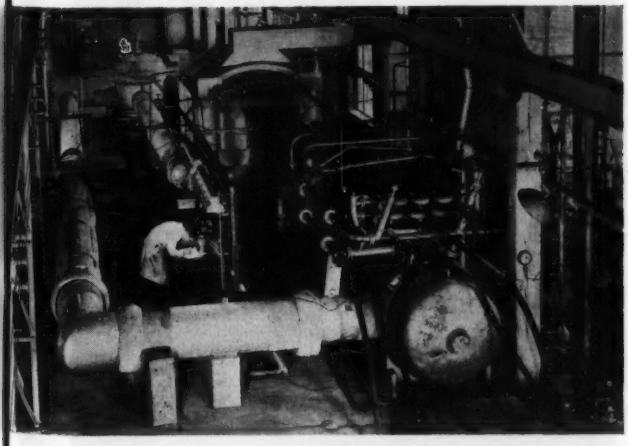


Fig. 2.—View of the present pressurized high temperature rig. See also Fig. 3.

Description of Test Matrices

A typical cross-flow basket represents a small section, 18 in. by 24 in. by 10 rows deep, of a nuclear power boiler. On the coolant side the 18-in. long tubes are connected up to form two parallel paths in the pressurized rig, and one path in the atmospheric rig. The test basket in the latter consists of a bolted plate assembly and uses flexible rubber U-bends to connect the coolant circuit. Rapid dismantling is thus possible.

A typical axial flow bundle consists of 24 tubes, 10-ft long, arranged on a triangular pitch and contained in an 18-in. diameter shell.

In all baskets correct side conditions are ensured by the use of dummy tube sections.

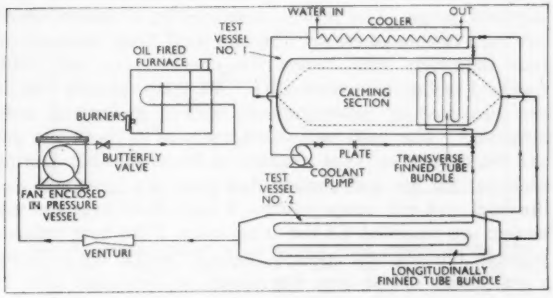


Fig. 3.—Schematic of the present pressurized high temperature rig. See also Fig. 2.

Experimental Technique

For each tube in every basket the bore, fin root diameter, fin diameter, number of fins per inch and fin thickness are measured. From these mean measurements a curve relating the outside gas film heat transfer coefficient to a coefficient based on the tube inside area is constructed, using the appropriate fin efficiency formulæ.[1] This curve is later used in the heat transfer evaluation for the particular tube arrangement. A typical curve is shown in Fig. 6.

The small length : diameter ratio of the tubes poses special problems in the determination of the inside film heat transfer coefficients of the coolant. It is considered that actual measurements are preferable to a calculation based on the standard correlations for very long tubes, and hence use is made of a modified Wilson Plot[2] technique, to be outlined below. It would, of course, be possible to make use of the alternative technique of tube wall measurement, but reliable or meaningful measurements cannot readily be obtained for transversely finned surfaces.

If the coolant-side heat transfer variables can be correlated by the equation

$$Nu = K\,Re^{0.8}\,Pr^{0.4}$$

where K is a constant

then
$$\frac{h_w d}{k} = K\left(\frac{\rho v d}{\mu}\right)^{0.8}\left(\frac{C\mu}{k}\right)^{0.4}$$

$$\therefore\ h_w = Jv^{0.8}$$

where
$$J = \frac{K^{0.8}C^{0.4}k^{0.6}}{\mu^{0.4}d^{0.2}}$$

Thus J is a function of coolant temperature only for a given type of tube.

Now
$$\frac{1}{U} = \frac{1}{h_w} + \frac{1}{h_{wall}} + \frac{1}{h_o}$$

$$\therefore\ \frac{1}{U} = \frac{1}{Jv^{0.8}} + \frac{1}{h_{wall}} + \frac{1}{h_o}$$

If the mean bulk temperature of each fluid and the mass flow rate of the outside gas are kept constant then the last equation may be expressed for a given tube size in the form:

$$\frac{1}{U} = \frac{A}{v^{0.8}} + B$$

where A and B are constants.

For each tube arrangement a series of tests is carried out, in the first place, at a constant gas rate and pressure and varying coolant rates. Gas and coolant temperatures are measured by chromel-constantan thermocouples directly in the fluid stream. All pipework is heavily lagged and thermocouples are individually calibrated against fixed points. Gas pressure is measured by a calibrated sub-standard gauge. Gas flow is measured by a venturi which has been calibrated by very careful total head traverses on four diameters (the calibration checks very well with standard orifice measurements). All thermocouple e.m.f.s are measured by potentiometer, with a melting-ice cold junction. The bulk mean temperatures of both the gas and the coolant are kept constant as far as possible. During each test the gas and coolant flow rates are measured and the inlet and exit temperatures of each fluid over the test section are recorded. (A test is accepted if the heat balance between the gas and coolant closes to within 5%.) From a knowledge of the heat flux based on the inside area of the tube and the logarithmic mean temperature difference between outside and inside fluids, the overall heat transfer coefficient U is calculated and plotted, as in Fig. 7, against

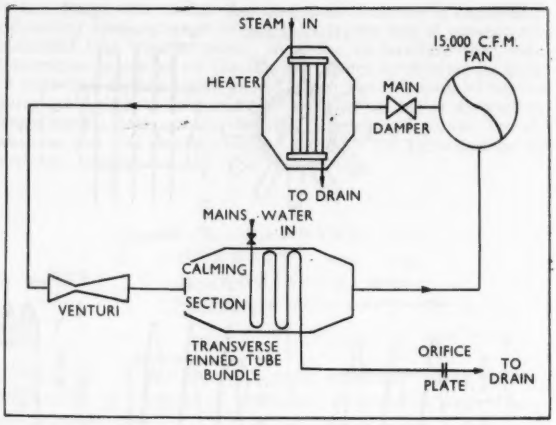


Fig. 4.—Line diagram of atmospheric pressure rig. See also Fig. 5.

the reciprocal of the coolant velocity raised to the 0.8 power. this curve being termed the "Primary" Wilson Plot. The best straight line is then drawn through the points by the method of least squares. The vertical intercept represents (approximately) the gas film resistance plus the wall resistance, the vertical distance from the intercept to any point on the line giving (approximately) the coolant film resistance for the particular coolant velocity and the mean bulk temperature. This primary Wilson plot is then refined, by making a suitable correction to each test point for the observed variation of the mean gas flow, gas temperature and coolant temperature from the overall mean values, enabling a "Secondary" Wilson Plot to be constructed as shown in Fig. 7. For any particular coolant velocity in the subsequent tests the coolant film resistance can be read off the secondary plot and appropriately corrected for the bulk coolant temperature of the test.

A series of experiments is next undertaken with the coolant rate kept constant but with various gas flow rates and gas pressures. The overall heat transfer coefficient U is calculated as described above for the variable coolant

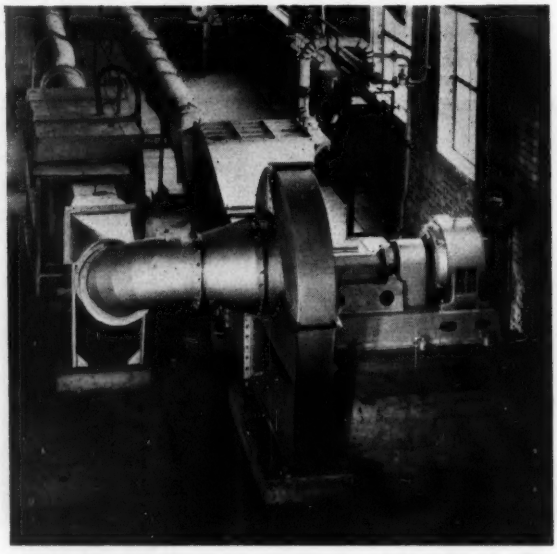
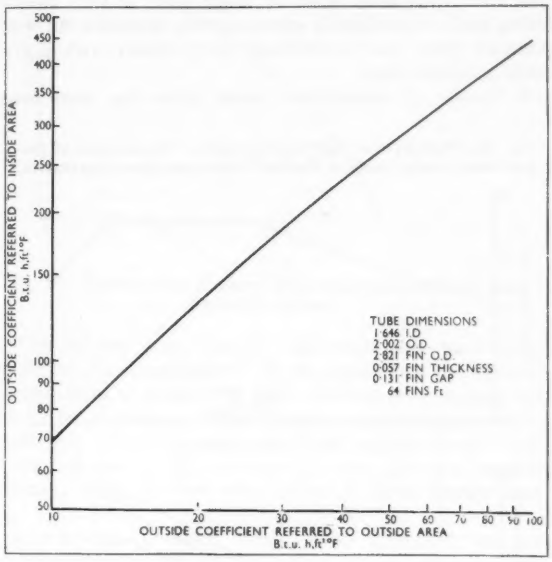


Fig. 5.—View of atmospheric pressure rig. See also Fig. 4.

tests. After expressing this value as a resistance the coolant film resistance (from the secondary Wilson plot) plus the wall resistance are subtracted from it. The residual resistance is due to the gas film on the outside of the tubes and can readily be expressed as a heat transfer coefficient referred to the outside area of the tubes by means of a graph of the form of Fig. 6. This coefficient is then used to evaluate a Nusselt number, incorporating the volumetric equivalent diameter of the tube matrix.

Fig. 6.—Typical fin efficiency curve.



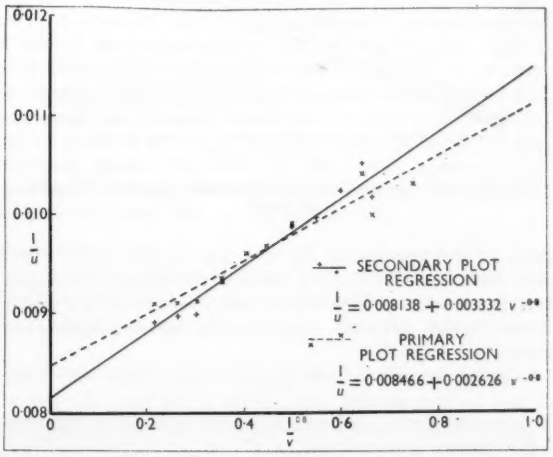


Fig. 7.—Wilson plot. Tubes 1.9 in. o.d., 1.61 in. i.d., with 36 fins $\frac{7}{16} \times 0.036$ in. on 3 in. equilateral triangle pitch (axial-flow bundle).

The Nusselt number, divided by the one-third power of the Prandtl number, is plotted against the Reynolds number. For axial-flow bundles the Reynolds number contains the volumetric equivalent diameter; for cross-flow bundles the Jameson equivalent diameter is used.[3]

Pressure drop measurements across the tube basket are made during each heat transfer experiment. The overall

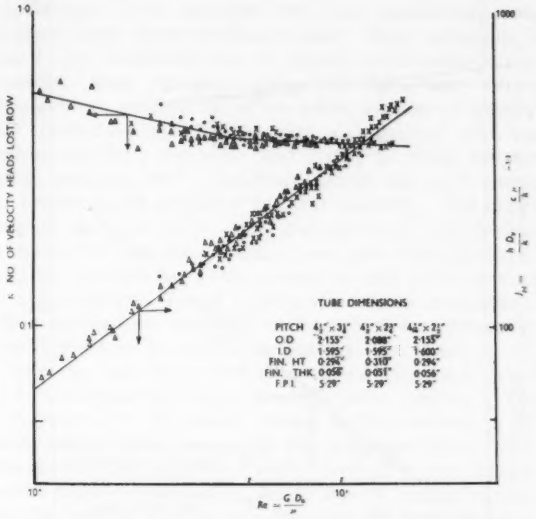

K = NO. OF VELOCITY HEADS LOST ROW
TUBE DIMENSIONS
PITCH 4½" × 3½" 4½" × 2½" 4½" × 2½"
O.D 2·155" 2·088" 2·155"
I.D 1·595" 1·595" 1·600"
FIN. HT 0·296" 0·310" 0·296"
FIN. THK. 0·058" 0·051" 0·056"
F.P.I. 5·29" 5·29" 5·29"

Fig. 8.—Heat transfer and pressure drop results for a transverse-finned tube on three staggered pitchings (cross-flow bundle).

pressure drop is measured by two Piezometer rings each consisting of 12 pressure tappings in the approach and exit ducts of the basket approximately 18 in. from the tubes. For accurate determinations a Betz high-pressure micromanometer is used. Gradient pressure drops down the basket are measured for axial-flow bundles only. It has been found impossible to obtain reliable gradient pressure drop measurements for cross-flow bundles on the high-pressure rig, because of side effects, and the results reported include any entrance and exit effects. Such effects are most readily investigated on the low-pressure rig by the successive removal of tube rows, and are found to be small. Pressure drops are expressed as velocity heads lost/row, for cross-flow bundles, and as a Fanning friction factor, incorporating the volumetric diameter, for

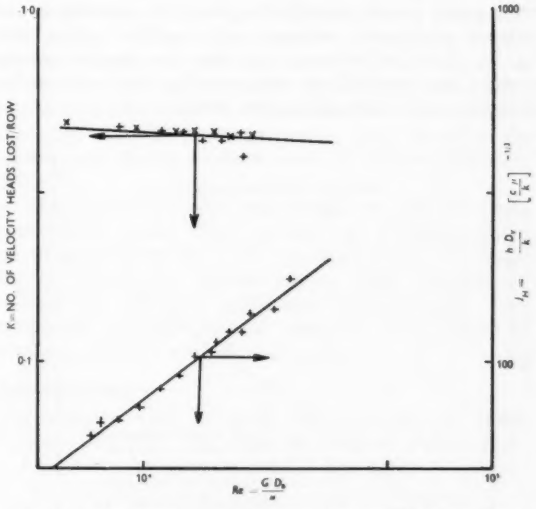


Fig. 9.—Heat transfer and pressure drop results (cross-flow bundle). Bundle dimensions: tube, $2\frac{11}{32}$ in. o.d. $\times$ $2\frac{1}{32}$ in. i.d.; fin, $^{29}/_{64}$ in. high $\times$ 0.062 in. $\times$ 5 f.p.i.; arranged in staggered pitch $4\frac{3}{8}$ in. normal to gas flow, and $3\frac{1}{16}$ in. parallel to the same. D_B (Jameson equivalent dia. = 0.00310 ft) D_V (volumetric equivalent dia. = 0.00596 ft).

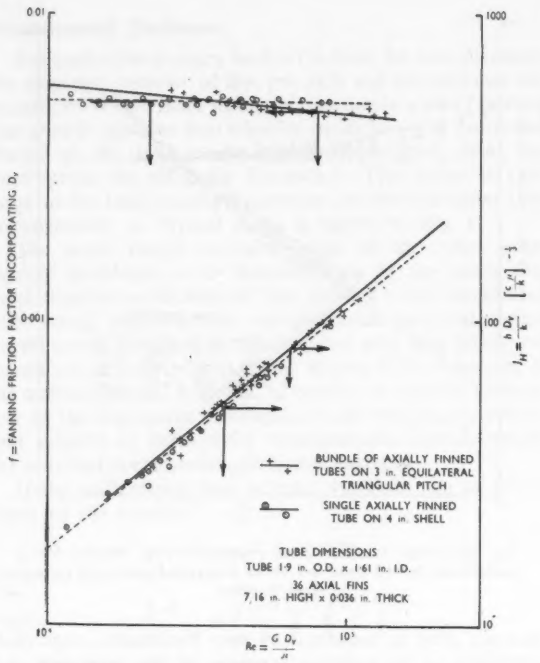

f = FANNING FRICTION FACTOR INCORPORATING D_v
$j_H = \frac{h D_v}{k}\left[\frac{c_p \mu}{k}\right]^{-\frac{2}{3}}$
$Re = \frac{G D_v}{\mu}$
BUNDLE OF AXIALLY FINNED TUBES ON 3 in. EQUILATERAL TRIANGULAR PITCH
SINGLE AXIALLY FINNED TUBE ON 4 in. SHELL
TUBE DIMENSIONS
TUBE 1·9 in. O.D. x 1·61 in. I.D.
36 AXIAL FINS
7/16 in. HIGH x 0·036 in. THICK

Fig. 10.—Heat transfer and pressure drop results for axially finned tube (axial-flow bundle and single tube).

axial-flow bundles. These parameters are plotted against Reynolds number.

Results

The original low-temperature pressurized rig was used to determine heat transfer and pressure drop correlations for gas in cross-flow over one particular size of transverse-finned tube in three different staggered pitch arrangements. These correlations have since been confirmed at high temperature (490°F bulk mean temperature as opposed to 220°F). It has been found possible to collect both heat transfer and pressure drop results for these three arrangements under single correlations, using the volumetric and Jameson equivalent diameters as described above (see Fig. 8). It is not believed that these correlations can be extended to cover different tube sizes, but only account for relatively small changes in tube pitch.

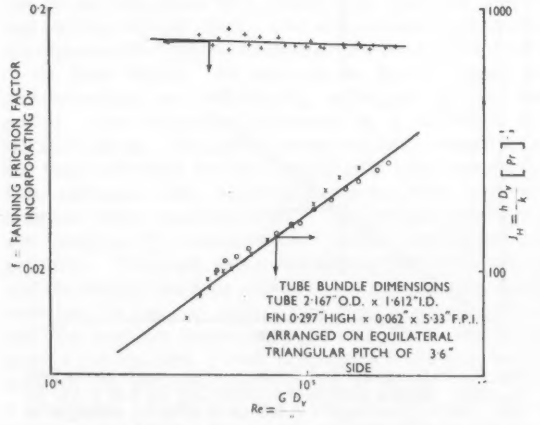

f = FANNING FRICTION FACTOR INCORPORATING Dv
$j_H = \frac{h D_v}{k}\left[Pr\right]^{-\frac{2}{3}}$
$Re = \frac{G D_v}{\mu}$
TUBE BUNDLE DIMENSIONS
TUBE 2·167" O.D. x 1·612" I.D.
FIN 0·297" HIGH x 0·062" x 5·33" F.P.I.
ARRANGED ON EQUILATERAL TRIANGULAR PITCH OF 3·6" SIDE

Fig. 11.—Heat transfer and pressure drop results for axial flow bundle (transverse-finned tube).

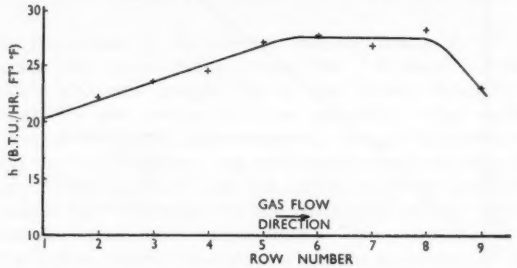
The results of tests on another type of transversely finned tube in cross-flow, obtained on the pressurized rig, are shown in Fig. 9. These tubes are, of course, of rather different dimensions from those first tested.

Of the types of tube which have been tested with gas in axial flow in the pressurized rig, two may be discussed.

The first of these, an axially finned tube, gave heat transfers of about 50% and pressure drops of about 75% of the data previously published for a single axially finned tube in a shell.[1] A test on a single axially finned tube of the same size in a 4-in. shell closely confirmed the results for the bundle (see Fig. 10 for both these results). Further tests have since been made on single tubes in very closely fitting shells, with slightly improved heat transfers but with pressure drops now conforming very closely with previously published data.

A bundle of transversely finned tubes has also been

Fig. 12.—Row-by-row heat transfer tests. Typical plot of gas-side heat transfer coefficient down 9-row cross-flow tube matrix.



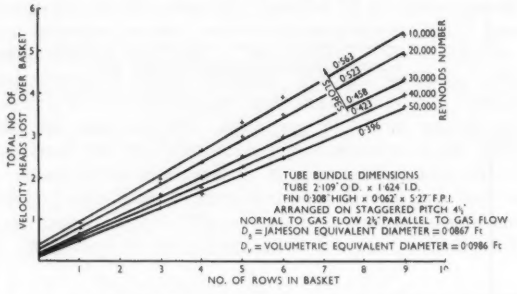

TOTAL NO OF VELOCITY HEADS LOST OVER BASKET
NO. OF ROWS IN BASKET
REYNOLDS NUMBER
10,000
20,000
30,000
40,000
50,000
TUBE BUNDLE DIMENSIONS
TUBE 2·109" O.D. x 1·624 I.D.
FIN 0·308" HIGH x 0·062" x 5·27" F.P.I.
ARRANGED ON STAGGERED PITCH 4½"
NORMAL TO GAS FLOW 2½" PARALLEL TO GAS FLOW
D_j = JAMESON EQUIVALENT DIAMETER = 0·0867 Ft
D_v = VOLUMETRIC EQUIVALENT DIAMETER = 0·0986 Ft

Fig. 13.—Row-by-row pressure drop tests (pressure drop/no. of rows).

tested in the pressurized rig with gas in axial flow. This gave heat transfer results closely confirming published data for a transversely finned fuel element in a circular channel,[4] but pressure drop results were considerably higher (see Fig. 11).

Most of the above tube baskets were tested with both air and carbon dioxide, but latterly it has been the policy to use only air, as this has not been found to affect the dimensionless correlations.

At present only cross-flow baskets have been tested on the atmospheric pressure rig. The heat transfer results agree closely with those for the pressurized rig, but friction factors are some 10% higher. An investigation is being conducted to determine the cause of this discrepancy, which is thought to be due partly to different inlet and exit conditions on the two rigs, partly to different levels of turbulence at entry, and partly to the aerodynamic noise mentioned previously. The atmospheric pressure rig has been modified to have entry and exit geometries identical with those of the high-pressure apparatus, and turbulence levels are being measured by hot wire anemometry.

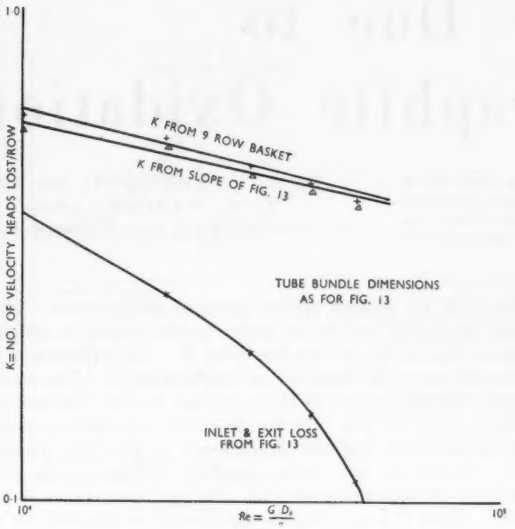

1·0
K FROM 9 ROW BASKET
K FROM SLOPE OF FIG. 13
TUBE BUNDLE DIMENSIONS AS FOR FIG. 13
K= NO. OF VELOCITY HEADS LOST/ROW
INLET & EXIT LOSS FROM FIG. 13
0·1
10⁴
Re = G Dₑ / μ
10⁵

Fig. 14.—Row-by-row pressure drop tests (velocity head loss/ Reynolds number).

Row-by-row heat transfer determinations have been made on the atmospheric rig by measuring the coolant temperatures at the end of each row and interpolating for the air temperatures. These revealed that the heat transfer coefficient builds up gradually from approximately 70% at the first row to 100% at the fifth row, and then remains constant until the last row, where it falls sharply (see Fig. 12).

Row-by-row pressure drops were estimated on the atmospheric pressure rig by making overall measurements on separate baskets consisting of 1, 2, 3, 4, 5, 6 and 9-tube rows. A graph of total velocity heads lost against number of rows in the test basket was drawn (see Fig. 13). For a given Reynolds number a straight line could be drawn, the slope giving the gradient pressure drop within the basket and the vertical intercept the loss due to end-effects. Fig. 14 shows a plot of the gradient pressure drop and the end-losses against Reynolds number. Also shown is the "gradient" pressure drop given by plotting one-ninth of the pressure drop over a nine-row basket.

Discussion

An experimental method has been evolved which gives very accurate results on the pressurized rig. Results from the atmospheric pressure rig are used for comparative calculations only, although they are considered more accurate than much published data. Much attention is paid to the standardization of primary data (temperature, pressure, mass velocity, etc.). It has been found advantageous to programme the entire method of calculation (including the Wilson plot calculations and the regressions) for a computer, and it may be noted that for design purposes 99% Confidence Limits are used (upper for pressure-drop and lower for heat transfer). The rather unusual heat transfer and pressure-drop correlations presented for cross-flow bundles have been found useful in that they account for small changes in tube pitching, such as are sometimes found necessary in boiler evaluations. These correlations, however, do not allow for changes in tube dimensions as evident, comparing Figs. 8 and 9.

Fig. 15.—Appearance of a flow visualization test on Perspex models.

Both the axial flow matrices discussed have been found to be unsuitable for use in nuclear power boilers. The performance of the axially finned tubing was especially disappointing, when compared with published data.[1] It is believed that the low heat transfer coefficients and friction factors measured are largely due to lack of mixing between the gas flowing between the fins and the bulk gas flow between tubes. Similar results have, of course, been found for axially finned fuel elements, leading to the use of helical fins and various "splitting" devices. The large pressure drops measured for gas flowing axially over a bundle of transversely finned tubes are not altogether surprising, although they do not agree with the data of Fortescue[4] (for single fuel elements in channels rather than bundles).

The row-by-row heat transfer measurements on the atmospheric pressure rig have given results which would be expected from published data for flow over bundles of unfinned tubes.[5]. The sharp fall in heat transfer coefficient over the last row is an interesting phenomenon which has not, to the authors' knowledge, yet been reported. Flow visualization tests on Perspex models have revealed substantial "loss of contact" of the flow on the downstream side of the last row, accompanied by large eddies extending nearly over the full tube diameter in width (see Fig. 15).

The gradient pressure drop and the end losses measured on the atmospheric rig have indicated that the measurement of the overall pressure drop on a nine-row basket gives design data sufficiently accurate for use in nuclear power boilers. Thus, using Fig. 14 to design a 27-row boiler tube bank, the nine-row data give a pressure loss of $27\times0.48=13.0$ velocity heads at Reynolds No. 3×10^4. The gradient data plus the end-losses give a pressure loss of $27\times0.46+0.2=12.6$ velocity heads. Thus the use of the nine-row data implies a safety factor of $((13.0-12.6)/12.6)\times100=3\%$.

In this paper it has only been possible to discuss certain representative results from the two rigs described, but a large programme of systematic work on extended surface tubes is under way, backed up by more fundamental investigations involving turbulence measurements, flow visualization and mass transfer analogies. It is hoped to report more of this work in due course.

Acknowledgment

The authors wish to thank the directors of Head, Wrightson and Co., Ltd., and the Nuclear Power Plant Co., Ltd., for permission to publish this paper.

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Thermal Instability Due to Graphite Oxidation

The oxidation of graphite by air is strongly exothermic with a high positive temperature coefficient at all practical temperatures. Under conditions in which the heat generated by oxidation exceeds that lost to the surroundings, the graphite temperature must rise at an increasing rate until halted by a new source of heat loss. Very high temperatures can result.

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The model used in the theory is that of a regular graphite lattice penetrated by parallel channels carrying a coolant air flow. Heat is generated by oxidation in the graphite, conducted to the channel wall, and there transferred by forced convection to the air. The effect due to longitudinal heat transfer within the graphite is assumed to be negligible, and calculation shows that this assumption is likely to be well justified.[1]

The rate of heat generation due to oxidation in a volume V of graphite at temperature θ may be expressed as :

$$H = VCk \exp(-E/R\theta) \text{ cal/sec}$$

and the rate of heat loss to the coolant air over the corresponding surface area S as :

$$H' = Sh(\theta - \theta_a) \text{ cal/sec}$$

For the graphite and air to be in thermal equilibrium, $H = H'$, and therefore

$$k = \frac{Sh}{VC}(\theta - \theta_a) \exp(E/R\theta)$$

$$= \frac{ph}{AC}(\theta - \theta_a) \exp(E/R\theta)$$

or

$$k = a(\theta - \theta_a) \exp(b/\theta) \quad \ldots\ldots\ldots \quad (1)$$

which gives the equilibrium graphite temperature for given values of k and θ_a. As impurity pick-up[2] and pile irradiation[3] cause large variations in the graphite reaction rate, k must be treated as a variable.

The information given by equation (1) is conveniently presented as the series of curves obtained by plotting k (on a log scale) against θ at constant values of θ_a. A typical series of such curves, calculated for the rig described below is shown in Fig. 1. Their significance is most easily understood by comparison with the heat generation and heat loss curves (Fig. 2). In Fig. 2(a) the rates of heat generation and heat loss are plotted against graphite temperature. Three heat generation curves are given, corresponding to different values (k_1, k_c, k_2) of the reactivity k. Also plotted is the heat loss curve for the given air temperature θ_a. The second heat generation curve (with $k = k_c$) just touches the heat loss curve at C. In Fig. 2(b) the reactivity k is plotted against the equilibrium graphite temperature as given by equation (1). Points on this curve therefore correspond to intersections of the heat generation and heat loss curves in Fig. 2(a). Thus if $k = k_2 > k_c$, no equilibrium is possible for the given air flow and temperature.

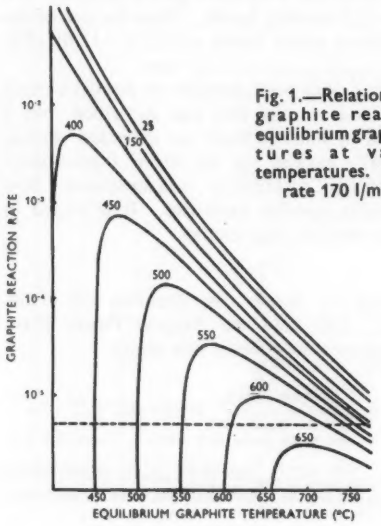

Fig. 1.—Relationship between graphite reactivity and equilibrium graphite temperatures at various air temperatures. Total airflow rate 170 l/min at 25°C.

On further inspection of Fig. 2, the following points emerge :

(1) If $k = k_1 < k_c$. Figs. 2(a) and (b) both show two equilibrium temperatures (corresponding to points A and B). The equilibrium state is stable or unstable according as $dH/d\theta$ is less than or greater than $dH'/d\theta$. Fig. 2(a) therefore shows A to be a stable state, and B an unstable state.

NOMENCLATURE

H	Rate of heat generation due to oxidation in a given volume of graphite, cal/sec
H'	Rate of heat loss to the coolant air over the corresponding cooled surface, cal/sec
V	Volume of graphite oxidizing, cm³
S	Corresponding cooled surface area, cm²
k	Reaction rate of the graphite in air at 400°C, h⁻¹
C	$\frac{\rho \Delta H}{3600 \text{ (A.W.)}} \exp(E/673R)$
ρ	Graphite density, g/cm³
ΔH	Heat of oxidation of graphite, cal/g atom
A.W.	Gramme-atomic weight of carbon
E	Activation energy for oxidation, cal/g atom
R	Universal Gas Constant, cal/g atom, °K
h	Heat transfer coefficient (graphite to air), cal/cm², sec, °K
p	Perimeter of channel, cm
A	Cross-sectional area of graphite associated with each channel, cm²
a	ph/AC
b	E/R
x	Distance along channel, cm
x_c	Distance of critical point along channel, cm
w	Mass air flow per channel, g/sec
c	Specific heat of air at constant pressure, cal/g, °K
θ	Graphite temperature, °K
θ_a	Air temperature, °K
θ_m	Unstable equilibrium graphite temperature, °K
θ_s	Stable equilibrium graphite temperature, °K
θ_c	Critical graphite temperature, °K
θ_{ac}	Critical air temperature, °K
θ_1	Graphite temperature at point x_1, °K
θ_{a1}	Air temperature at point x_1, °K

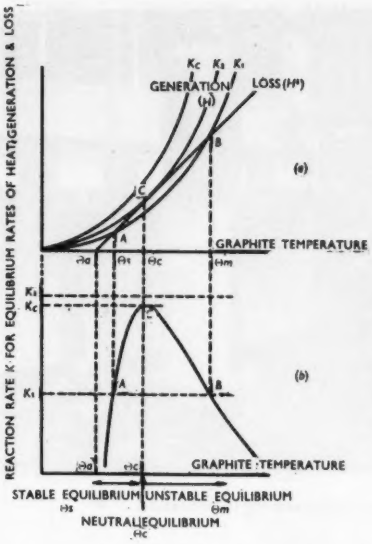

Fig. 2.—Correlation between the curves (a) Rates of heat generation and heat loss versus temperature (b) equilibrium temperatures versus reactivity.

The graphite temperature at B is the maximum graphite temperature that can be cooled by the given air flow at temperature θ_a, and is denoted by θ_m. Any slight displacement of the graphite temperature from θ_m causes a further increasing divergence. A small decrease results in point A eventually being reached, while a small increase causes a further self-promoting and indefinite rise. (The rise must eventually be halted by some mechanism not considered here, e.g., lateral heat loss or diffusional control of oxidation.)

(2) If $k=k_c$. This is a special example of the previous case, obtained by increasing k until A and B coincide. The state is then one of neutral equilibrium. In Fig. 2(a) the heat generation and heat loss curves now only meet at one point C, and thus, in Fig. 2(b), k_c is the ordinate of the maximum point. The graphite temperature is called the "critical graphite temperature," denoted by θ_c, and is given by :

$$H=H'$$

and

$$dH/d\theta=dH'/d\theta$$

whence

$$\theta_c^2 \exp(b/\theta_c)=kb/a \quad . \quad . \quad . \quad . \quad . \quad (2)$$

also

$$\theta_{ac}=\theta_c(1-\theta_c/b) \quad . \quad . \quad . \quad (2a)$$

In a long channel of homogenous graphite, the graphite and air may be in stable thermal equilibrium as given by equation (1) (point A in Fig. 2). The graphite and air temperatures rise along the channel, as P, Q, R in Fig 3, until the critical temperatures are reached at C. If the temperatures rise further, a self-sustaining runaway results. The length of channel after which critical conditions will result from given inlet conditions (assuming thermal equilibrium up to the critical point) can be obtained as follows :—

The rate of increase of the air temperature along the channel is given by :

$$d\theta_a/dx=hp(\theta-\theta_a)/wc$$

and as before, for equilibrium

$$k=a(\theta-\theta_a)\exp(b/\theta)$$

Eliminating θ_a, and integrating along the channel from the inlet graphite temperature θ_1 at x_1, to the critical graphite temperature θ_c at x_c, we have :

$$(x_c-x_1)=\frac{wc}{ACk}\left[\int_{\theta_1}^{\theta_c} e^{b/\theta}\,d\theta+\frac{kb}{a}\left(1/\theta_c-1/\theta_1\right)\right]$$

The integral in this expression can be evaluated numerically, and so the distribution of graphite temperatures along a channel obtained. The air temperature at any point is given from the graphite temperature by equation (1).

The distribution of graphite and air temperatures along a channel has been calculated for the experimental rig described below. The curves for two of the air flows used are given in Fig. 4. These curves are given for a channel of indefinite length, but the distribution in a channel of given length is very easily obtained. For example, with a flow rate of 170 l/min, a channel 123 cm long (corresponding to the eight blocks in the rig) with an inlet air temperature of 500°C should take up the temperature distribution between points A and B on Fig. 4. With the inlet at 505°C the same channel would have the distribution between A′ and B′, and so on. The air inlet temperature with which the outlet end would just become critical can be read off as 508°C for a flow rate of 170 l/min.

The values of the various parameters appropriate to the rig are such as to result in the prediction of high temperature gradients and rates of change of temperature gradient towards the critical point; longitudinal conduction in the graphite and radiation from block to block will undoubtedly modify the temperature distribution. The values for reactors are, however, such as to make this effect much smaller (e.g. refs. 2–6).

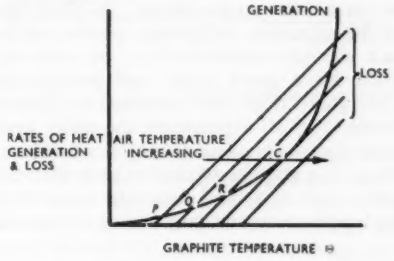

Fig. 3.—Approach of critical condition by increasing air temperature.

Predicting Safe Conditions

The present simple approach is of value because of the ease with which maximum permissible temperatures can be deduced from measurements of graphite reaction rate at many places in the reactor. To sum up the points of significance arising from Fig. 1:

(a) If the air temperature at any point rises to a value such that the graphite reaction rate at the point is higher than the maximum of the appropriate k/θ curve (e.g. $k=k_2$ in Fig. 2), then the condition is adversely unstable, *whatever the graphite temperature*. The critical air temperature θ_{ac} is that for which the maximum of the k/θ curve coincides

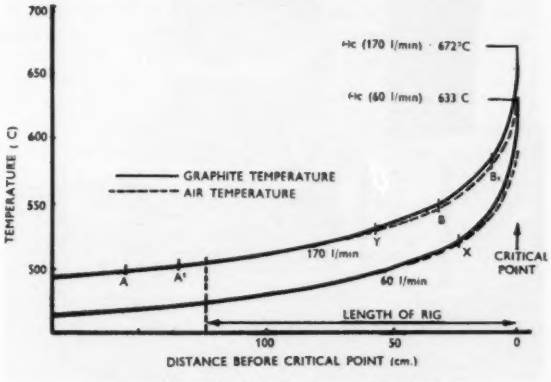

Fig. 4.—Theoretical temperature distributions along the experimental rig.

with the applicable value of k, and is the absolute maximum air temperature tolerable with the given air flow and reactivity.

(b) Even if the air temperature is somewhat lower than θ_{ac}, so that the prevailing reaction rate is below the maximum in the k/θ curve (e.g. $k=k_1$ in Fig. 2), there is still a maximum permissible graphite temperature (θ_m) above which the graphite cannot be cooled.

The main drawback of this approach lies in the difficulty of estimating the air temperature at a point. Fortunately, however, the k versus θ curve is strikingly insensitive to air temperature provided the "critical" conditions are not closely approached. Thus a change of 300°C in the air temperature causes a change in θ_m of the order of 30°C only. A very rough estimate of the air temperature therefore leads us to no greater error than a typical uncertainty in the value of k.

Experimental Rig

It was considered desirable to obtain some experimental confirmation of the theory and the "graphite burning rig" was accordingly constructed (Fig. 5). It consisted of a vertical stack of eight blocks of reactor-quality graphite (situated in sections 2 to 9 inclusive), with a series of ¼-in. dia. holes on a 1-in. square lattice. A small lattice pitch was used to minimize diffusional control of oxidation. Each block was surrounded by ½ in. of insulating cement with outside this a guard heater, and temperatures of the graphite and guard rings were measured by chromel/alumel thermocouples. In all experiments the mean temperatures of the guard heaters were kept as near as possible to those of the corresponding graphite blocks, so as to minimize lateral heat transfer. Air at a fixed flow rate was preheated to a given inlet temperature, and then passed up the stack.

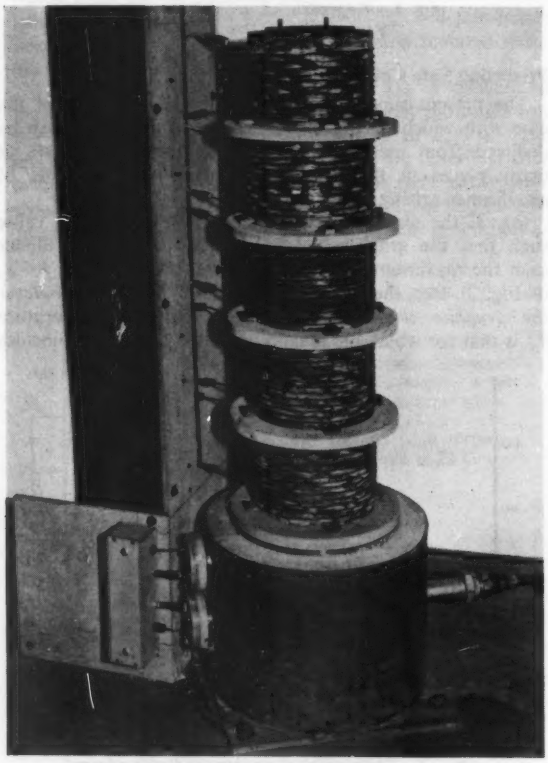

Fig. 5.—Graphite burning rig in course of construction.

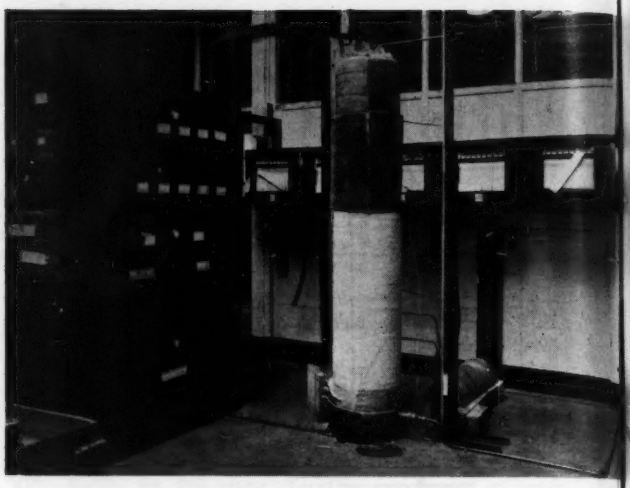

Fig. 6.—Completed rig in operation.

In each run the object was to set the air flow and inlet temperature to the desired values, continually adjust all guard heaters to the graphite temperatures, and observe the sequence of events. Before each run, the guard heaters were used to preheat the graphite to about the same temperature as the inlet air, thus speeding up the experiments. The exit gas was analysed for CO and CO_2 when it was thought that a significant proportion of the oxygen entering the rig might have been consumed.

Experimental Results

The condition and results of the main runs are given in Table 1, and the course of salient parts of some of these is illustrated in Figs. 7 and 8. Where the general trend of the temperature distribution is not followed, the curve is dotted. The air inlet temperatures are also plotted.

It had been hoped that a stable temperature distribution following the theory would be obtained, but in practice the design of the rig made it impossible to reduce lateral heat loss to such a level that this occurred. If the inlet and initial temperatures were below a certain value, a general cooling resulted, if above this value, a continuous temperature increase was observed. This minimum inlet temperature for runaway provided the experimental test of the theory. Table 1 shows that this temperature is rather insensitive to air flow, being about 520°C at 60 l/min and 530°C at 170 l/min.

The theoretical results of given inlet conditions can be deduced from Fig. 4 as explained above. Thus, with an air inlet temperature of 520°C at 60 l/min or 530°C at 170 l/min (points X and Y of Fig. 4), a critical condition would develop within the length of the rig, according to the assumptions of

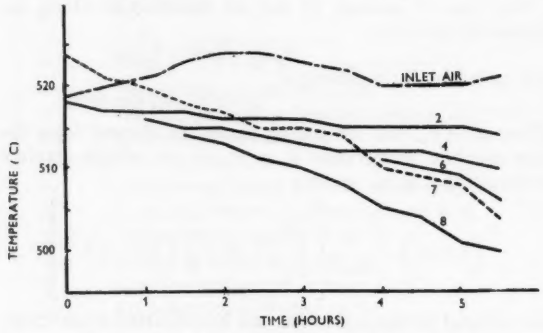

Fig. 7.—Run 3 (1). General fall in temperature.

TABLE 1. CONDITIONS AND RESULTS OF MAIN RUNS

Run	Air flow litres/min at 25°C	Air inlet temp., °C	Result	Remarks
2(1)	60	520	All temps. decreased	
2(2)	60	540	All temps. increased	
2(3)	60	530	Temps. increased slowly	
2(4)	60	525	Temps. increased very slowly	Graphite replaced after this run
3(1)	170	520	All temps. decreased	See Fig. 7
3(2)	170	530	Temps. decreased very slowly	
3(4)	170	540	Temps. increased rapidly	
3(6)	110	545	Temps. increased	Allowed to rise 20°C then air flow increased 2½ times
	280	545	Temps. still increased	
3(7)	30	535	Temps. increased	Allowed to rise 20°C then air flow increased 9 times
	280	535	Temps. still increased	
3(8)	15	540	Temps. increased	Flow increased when some graphite reached 600°C. Exit gas then contained 7.8 vol.% CO_2 1.4 vol.% CO
	280	540	Temp. rise accelerated, especially at outlet end	
3(9)	280	550	Temps. increased Increase allowed to continue indefinitely	See Fig. 8

the theory. The actual observation of this provides adequate confirmation of the theoretical predictions.

The values of 520 or 530°C, observed as the minimum air inlet temperatures for runaway at the two flow rates, are to be compared with the values 475 or 510°C obtained from Fig. 4 as the minimum air (and graphite) inlet temperatures which could possibly lead to thermal instability. As the rates of heat evolution at these temperatures are quite small (~12 W/block at 500°C), a small lateral heat loss could easily account for the difference. The small effect of longitudinal conduction in the graphite would also create a trend in the same direction.

Other results of qualitative interest were obtained, notably:

(1) The difficulty of "blowing out" a runaway once started;

(2) A runaway started with a low air flow was frequently accelerated by increasing the air flow, the initial moderate rate being due to restriction of the oxidation by air starvation.

(3) The ultimate course of a runaway was examined and the results are given in Fig. 8.

By the time the temperature of the outlet end had reached 650°C the radiation heat loss from the top of the rig had

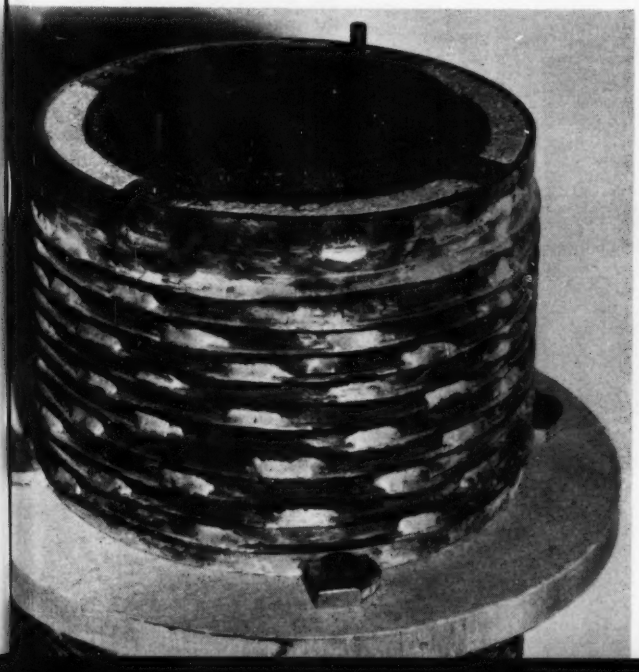

Fig. 9.—Detailed section of graphite rig.

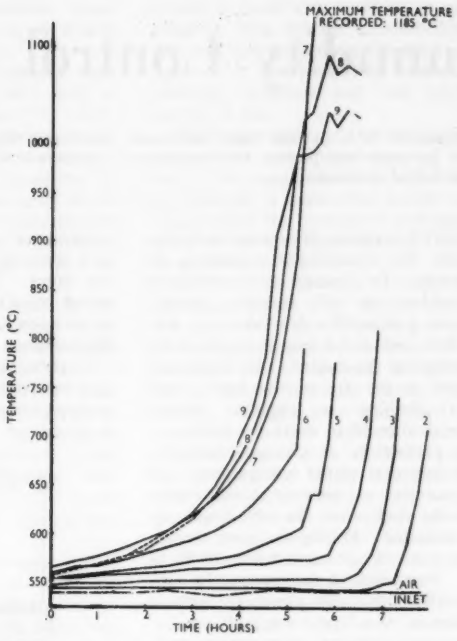

Fig. 8.—Run 3 (9). The eventual course of a runaway.

been overcome and the graphite temperature varied uniformly from section to section. The temperature rose most rapidly in the hotter upper sections, and above 700°C extremely rapid rises were observed, despite the fact that the guard heaters lagged behind the graphite by as much as 50°C at 800°C and more at higher temperatures. Blocks 8 and 7 followed rapidly after block 9 and the highest temperature recorded was 1185°C (in block 7). The curve for block 7 up to this point would suggest that the highest temperature attained was considerably higher than this. The other blocks in order underwent the rapid rise at somewhat longer intervals, and the high temperature wave passed right down the stack in four hours.

When half the stack had run away, the exhaust funnel was raised from the top of the rig. A large blue flame was observed, and this continued for the rest of the experiment. The exit gas at this time contained 6.3 vol.% CO and 14.3 vol.% CO_2.

Although any extrapolation of these qualitative results to other structures and conditions must be of doubtful validity, the indications are :

(a) If a large part of a graphite-air reactor should reach dangerous temperatures under shut-down conditions, the application of full coolant flow would have at best a very slow cooling effect and may be too late to prevent fire at the outlet end of the danger zone.

(b) The rapidity of propagation of the fire was extremely striking, and suggests that once a runaway condition is well under way there is little hope of preventing the spread without taking very drastic measures.

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Humidity Control During Boiler Erection

Condensation in a nuclear heat exchanger shell can be prevented by installing special purpose equipment for continuous temperature/humidity control during the period of erection.

By A. S. MILLER
(Dir., Denco Miller, Ltd., Hereford).

ON-SITE erection of a nuclear boiler calls for exceptional standards of cleanliness. To reduce to a minimum the infiltration of foreign matter, elaborate precautions are taken to prevent dust and dirt being brought in by men entering the boiler. Air locks are arranged at the top of the boiler, and special clothing is required before anyone is allowed to enter the boiler.

But prevention of contamination by dirt is only part of the requirement: it is also essential to prevent condensation within the shell while the tube banks are being installed. During this time outside temperatures may vary from 25°F to 80°F. Furthermore, the space to be conditioned is continually changing form as the nests of tube banks are built up.

For these reasons, any temperature/humidity control system must be extremely flexible. It must also be capable of running continuously without attention, and another desirable feature is portability so that the unit can be moved easily from one boiler shell to another.

At Berkeley, a study of these conditions was made by a specialist subcontractor, Denco Miller, Ltd., of Hereford. Special-purpose plant subsequently designed and installed by the company has now completed several thousand hours of satisfactory service.

During the first stages of erection when the boiler is empty, no special problems arise, except in mid-winter when any exposed uninsulated portion of the shell is subject to outside air temperature changes. When tubing commences, however, three problems arise. First, there is a resistance offered to the passage of air. Second, incoming conditioned air is cooled by the tubes and tends to pocket in regions between the tubes. Third, the portion of tubes which enter the boiler shell are, at times, at very low temperature in winter, due to their contact with the shell.

Stratification of the air, due to the varying temperature changes during its passage through the boiler and tubes, has a profound effect on the distribution,

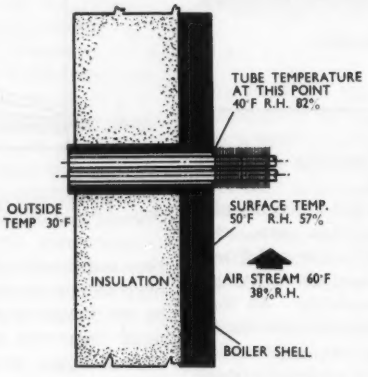


Fig. 1.—Temperature and humidity at shell and tube surfaces.

which becomes increasingly noticeable as tubing commences. Assuming the boiler is insulated before clean conditions commence, the shell is slow to respond to ambient temperature changes, except the tube ends which are, at all times, fully exposed and responsive to ambient conditions.

To achieve a satisfactory circulation through the boiler tube nests necessitates a pressure differential in the region of 1 in. W.G. at 1,500 c.f.m. The condition of the air in respect to moisture content and temperature has been evolved after a considerable amount of research.

First, investigation was carried out on a 3 h.p. refrigeration dehumidifier capable of providing a maximum of 1,000 c.f.m. at a minimum dew-point of 36°F, the average air delivery temperature being in the region of 60°F without the heaters on. With heaters in circuit it was able to control the temperature at 85°F to 90°F, the relative humidity at the higher temperature being 16% and the moisture content 0.005 lb of moisture/lb of dry air. During its passage into the boiler the air was cooled to an amount depending upon the ambient conditions, but generally settled in winter to between 55°F and 60°F. The corresponding humidity at the latter figure was generally 38% to 40%.

Fig. 1 illustrates how the temperature and the relative humidity are related at the boiler and the tube surfaces. The importance of the various surface temperatures will be appreciated. These conditions are extremely local to the surfaces, and a matter of a few inches away the conditions improve. It is possible to improve the conditions inside the boiler by increasing the temperature of the ingoing air by, say, 20°F, so that all of the surface temperatures inside the boiler are correspondingly raised. For example, if the airstream temperature were increased to 90°F, the moisture content of the air being the same, the relative humidity would fall to 11%. Assume that the boiler surface temperature rose to 65°F, then the relative humidity local to the boiler face would fall from 57% to 33%. This might seem a simple solution, but there are two serious objections. First, the condition inside the boiler would be most objectionable from the human comfort angle for the men working inside and, second, a more serious objection would be the effect of an electrical power failure which, in turn, would cause a failure of the heat source.

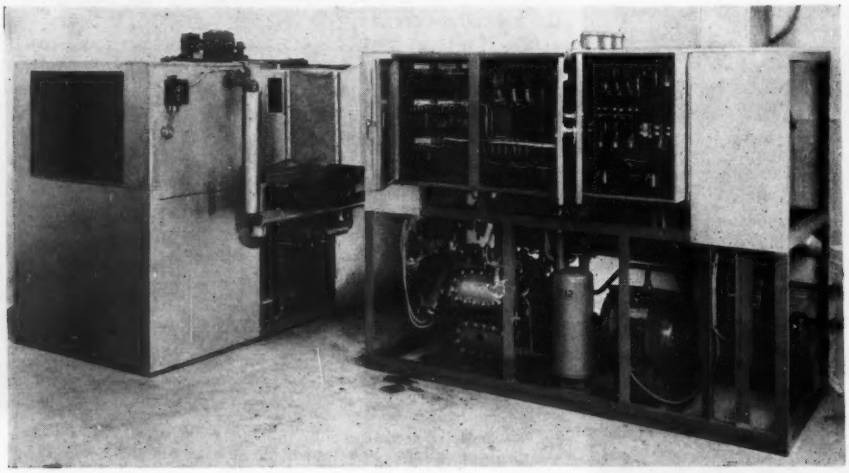


Fig. 2.—Denco Miller dehumidification plant, 2,000 c.f.m. capacity; dew point −10° C.

If the conditions within the boiler were maintained at 70°F, 30% relative humidity, a fall in temperature of 15°F would raise the relative humidity to 50%, which would be considered a danger condition over any period longer than, say, five hours. If the boiler were tubed, or partly tubed, the condition would be serious. A high temperature is clearly the wrong approach to the problem. A maximum relative humidity of 30% at a temperature between 50°F and 60°F would be satisfactory both from the point of view of working conditions and the maintenance of good storage conditions for the metal. However, 30% relative humidity at 60°F does not allow much margin, particularly in winter. It was, therefore, decided that the ideal condition to be achieved was 20% relative humidity at 50°F. This condition allows sufficient margin in hand from the time angle for any faults to be rectified.

To achieve these conditions a plant was designed with an operating dew-point temperature of −10°F, a maximum airflow of 2,500 c.f.m. and a controlled outlet temperature of 50°F to 60°F. The system employs the regenerative heat pump cycle to condition the air and is designed for non-recirculation.

The possibility of recirculating the conditioned air was considered as it would have enabled the capacity of the plant to be reduced. Unfortunately, there are

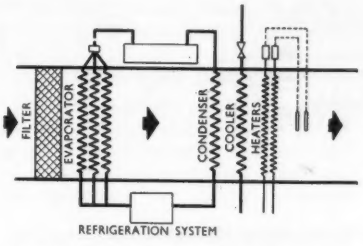


Fig. 3. Basic circuit of temperature/humidity control system.

two problems to contend with in this arrangement. First, the return air duct would be difficult and costly to instal; second, the uric acid content of the air within the boiler would be increased. Experiments with recirculated air were carried out using flexible ducts, but the results did not prove sufficiently advantageous to warrant the adoption of this method, bearing in mind the difficulties involved. Also, the number of men inside the boiler had to be limited to keep the uric acid content down, even allowing for the fact that there was a good percentage of fresh-air make up.

With a non-recirculation system, it is impracticable to maintain the same temperature of air constantly because the load varies greatly from day to day, according to the condition of the air being drawn in. For instance, on a cold, dry winter's day at 30°F, air may only contain 0.003 lb of moisture/lb dry air, whereas in summer it may contain 0.012 lb moisture/lb dry air. The quantity of conditioned air is, therefore, automatically regulated so that it is within the capacity of the plant.

The recommended requirements were consequently established as 20% R.H. at 50°F to 55°F in winter and 30% R.H. at 65°F in summer and a minimum airflow of 1,500 c.f.m.

To achieve the 65°F condition in summer, the plant had necessarily to be of the type employing the refrigeration method of drying. Other influential factors affecting the design were as follows:—

(1) Some measure of control of the dry bulb temperature was called for so it was necessary to incorporate a method of reheat with automatic regulation.

(2) The latent and sensible heat quantities involved in reducing the air to the condition required vary from 20,000 B.t.u./h in the coldest winter condition to 80,000 B.t.u./h in midsummer. To compensate for this, some form of automatic capacity control had to be incorporated.

(3) As the dew-point temperature is below the freezing point of water, an efficient and positive method of defrosting on a time-cycle basis was called for.

(4) The plant had to be completely automatic.

The plant installed incorporates two special heat exchangers designed to circulate chilled ethylene glycol at −16°C: one heat unit is automatically defrosted whilst the other is in operation. On leaving the cooler, the air passes through a series of heaters to bring the air back to a preset operating temperature. The air is then passed through a filter and into the boiler. Air circulation is by means of a centrifugal fan.

The refrigeration compressor is automatically capacity controlled, and is of the latest high-speed multi-cylinder pattern. The air temperature is controlled by multi-step thermostats, and the plant is time sequence controlled and designed for continuous automatic operation. It is constructed in two parts to facilitate handling and can easily be moved at site.

The temperature of the air leaving the evaporator varies between −7°C and 0°C. The temperature to which the air is reheated is controlled partly by the reheat from the condenser and partly by a series of electrical heaters controlled from thermostats.

Most of the reheat is provided by the condenser which is in the airstream, but the heat which this liberates can be controlled by a system whereby some of the gases are able to condense in a secondary cooler remote from the conditioned airstream. Therefore in winter all of the condenser heat is utilized, whereas in summer part of it is rejected so that the air entering the boiler is partly chilled. The dew-point temperature achieved during most of the winter period is −10°C with an airflow varying between 1,800 and 2,500 c.f.m. During summer the dew-point rises to 0°C.

The compressor has automatic capacity control which is regulated according to the load. This is a fairly necessary feature because the load variation can be as wide as 40% within a 48-hour period and unless the thermal storage capacity of the plant were very large, and this is impracticable with a portable unit, the compressor would be continuously cycling under light load.

The air circulating fan can deliver a maximum of 2,500 c.f.m. and this can be either manually or automatically controlled. When automatically controlled, the air quantity is adjusted to provide a constant dew-point temperature. The defrosting of the heat exchangers is by means of hot air and this operation is time sequence controlled.

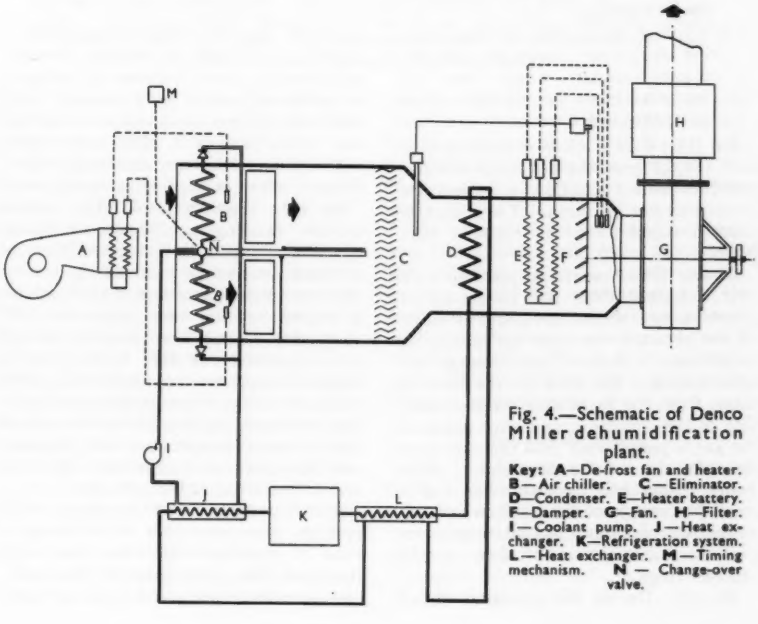


Fig. 4.—Schematic of Denco Miller dehumidification plant.

Key: A—De-frost fan and heater. B—Air chiller. C—Eliminator. D—Condenser. E—Heater battery. F—Damper. G—Fan. H—Filter. I—Coolant pump. J—Heat exchanger. K—Refrigeration system. L—Heat exchanger. M—Timing mechanism. N—Change-over valve.

Filtration in Reactor Gas Circuits

By P. J. FROGGATT,
(*Atomic Power Constructions, Ltd.*)

A major problem in the development of carbon dioxide-cooled nuclear plant is that of the filtration and collection of dust entrained by the gas. In the past, the cut-off properties of relevant filters have been rated by the American Specification MIL-F-5504A. A new filter satisfying more stringent demands has been developed and is described below.

THE development of the gas-cooled nuclear power station has presented many problems to the engineer and among these is one of filtration and collection of dust from the carbon dioxide in the reactor circuit. This dust, which will be radioactive, consists of small particles of graphite which erode from the core, scale from the pressure vessel, gas ducting and boilers, and any dust left in the circuit after erection.

All items of plant connected with the reactor circuit are manufactured and erected under a very stringent system of clean conditions and every effort is made to prevent dirt, dust and foreign matter being left in the reactor circuit. However, with such a vast area to clean these precautions cannot be entirely effective, and therefore a system of filtration is necessary.

The Problem

The filtration and dust collection problem as applied to the nuclear power station falls roughly into three groups:

(1) To clean the circuit of any residual dust at the time of start-up and to prevent the accumulation of dust in the reactor.

(2) To prevent the escape of radioactive dust by filtering all carbon dioxide released from the reactor circuit to the atmosphere.

(3) To filter the carbon dioxide entering equipment associated with the reactor circuit, which must be protected from the harmful effects of radioactive dust.

Re. (1). Civil nuclear stations have in each reactor generally 6-8 boiler circuits, and the coolant gas flow is maintained in each circuit by means of a circulator situated adjacent to the base of each boiler.

Due to the considerable pressure drop over a suitable filter and its associated pipework and valves, advantage is taken of the pressure rise over the circulator to produce a flow of gas through the filter system. The inlet to the filter is taken from the main duct on the outlet side of the circulator, and after filtration the gas is passed back into the circuit on the inlet side of the circulator. Each boiler circuit has its own filter and a small percentage of the gas flow in each circuit is continuously filtered, so preventing the accumulation of dust in the reactor circuit.

Re. (2). During the operating life of the station each reactor is periodically shut down for maintenance, and on each occasion it will be necessary to release the full reactor charge of carbon dioxide to the atmosphere. All gases released in this manner are filtered by the "blow-down plant" before exhausting to atmosphere. The blow-down plant consists of several filter units and a vacuum pump, the latter being used for "pump-down" operations to clear any part of the reactor circuit of carbon dioxide before entry for maintenance. Each boiler circuit and the plant associated with the reactor are connected into the blow-down system by separate runs of pipework, so that any individual section of plant can be vented separately if necessary. As with all pressure circuits, each reactor circuit capable of isolation is fitted with safety relief valves. Each boiler circuit and the pressure vessel has two valves and each valve is provided with a filter so that any discharge will be filtered before exhausting to atmosphere.

Re. (3). Filtration of the carbon dioxide entering equipment associated with the reactor calls for a positive type of filter; to give an example, it is very necessary that the carbon dioxide which is passed to the burst slug detection equipment is free from particles which are radioactive, as this would give a spurious count on the equipment. The charge machine, when engaged on charging operations, requires carbon dioxide at reactor circuit temperature and pressure, and here again it is important that this gas is free from heavy particles.

The foregoing brief summary will, perhaps, give some idea of the importance of filtration which has two vital functions, first protection of personnel and the public from radioactive dust and, secondly, the harmful effects of dust on equipment connected with the reactor circuit.

Filter Performance Specifications

A study was made of the available types of filter to perform these duties and after careful investigations it was decided for technical as well as economic reasons to develop an alternative system.

With a background of considerable experience in the design and manufacture of high-grade sintered bronze microfilters for high-pressure hydraulic circuits, the Hydraulics Division of Fairey Aviation were asked by A.P.C. to investigate if this type of microfilter was suitable for the filtration of carbon dioxide under the conditions prevailing in the reactor circuit.

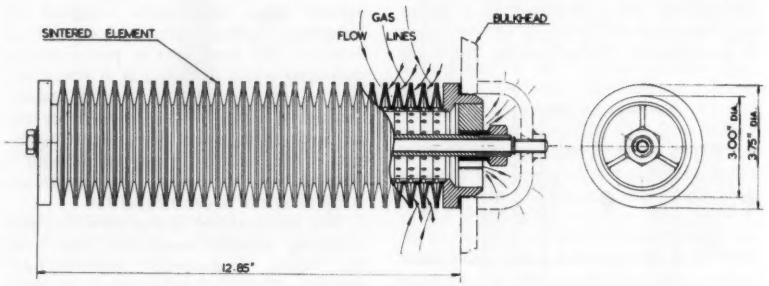


Fig. 1.—A complete filter element of the Fairey Microfilter-type.

The degree of filtration demanded is 100% at 5 microns for the filters in the reactor circuit, and 100% at 3 microns for the filters handling all exhaust carbon dioxide.

In the past all filters have been rated, in their cut-off characteristics, by the American Specification MIL-F-5504A. This specification permits a filter to be classified as a 5-micron filter if it will stop 98% of all contaminants larger than 5 microns which are subjected to it, but does not in any way classify the size of the remaining 2%. Such a filter can, therefore, transmit particles of, say, 40 microns and satisfy the specification. Where the filtration of radioactive particles to atmosphere is concerned, the passing of such large particles could be a considerable embarrassment.

As a result of an extensive research and development programme the Fairey Microfilter was made to the company's

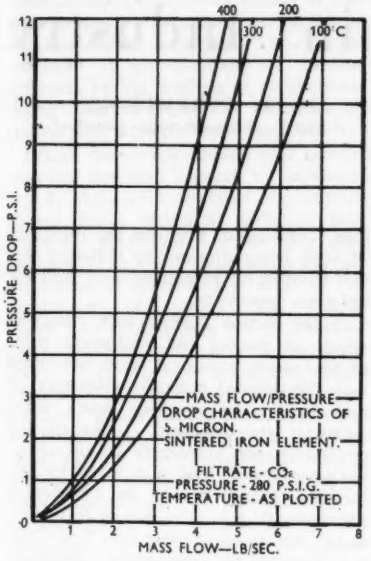


Fig. 2.—Calculated mass flow pressure drop characteristics of 5-micron element (standard 30-capsule pack).

own, and more stringent, specification. Thus a filter may be classified as "X" micron if it will stop 99.95% of all contaminants larger than "X" microns which are subjected to it, and will pass no particles greater than 1½ "X" microns in the remaining 0.05%.

New Filter Design

The sintered bronze element cannot be used for filtration in the reactor circuit due to its incompatibility, and therefore the production of a sintered iron filter was undertaken by Fairey in close collaboration with Bound Brook Bearings Ltd., producers of the sintered bronze discs. The outcome of the development was a sintered iron disc with a 5-micron characteristic to the Fairey specification. The iron disc was found to have considerable resistance to thermal shock, excellent permeability and an economic price, and was therefore adopted for the Fairey type of gas filter.

A complete filter element is shown in Fig. 1 and consists of 30 capsules, with each capsule composed of two discs mounted in a stack, the complete assembly appearing in the form of a bellows giving maximum flow area for minimum overall bulk. The discs have the shape of dished washers and are resistance welded together around the outer edge, the inner edges fitting around a radially drilled spacer ring. A seal is interposed between each capsule, and the whole assembly is pulled up tight by a central bolt. Gas flow is from the outside of each capsule, through the sintered metal and radial holes of the spacers, and so along the axis of the unit to the discharge exit. The sintered elements are supported from a diaphragm and are removable if necessary.

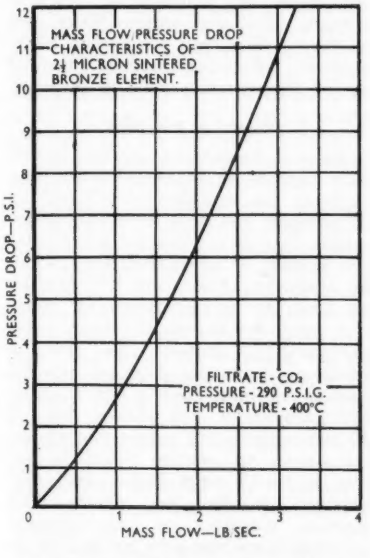

MASS FLOW PRESSURE DROP CHARACTERISTICS OF 2½ MICRON SINTERED BRONZE ELEMENT.
PRESSURE DROP—P.S.I.
FILTRATE - CO_2
PRESSURE - 290 P.S.I.G.
TEMPERATURE - 400°C
MASS FLOW—LB SEC.

Fig. 3.—Calculated mass flow pressure drop characteristics of 2½-micron element (standard 30-capsule pack).

Both the sintered iron and bronze have an overall length of 12 in. and have a diameter of 3.75 in., giving a total surface area of 375 in.^{2} At 12 p.s.i. pressure differential, one square inch of the Fairey Bound Brook iron element will pass 5.5 ft^3 per minute of air at 17°C; therefore, the complete Fairey filter as illustrated will pass 2,050 ft^3 per min at 12 p.s.i. differential, which is a very high gas flow for so compact a unit.

The mass flow pressure-drop characteristics as shown on Figs. 2 and 3 are obtained from calculations based on actual test results, and are applicable to standard element packs consisting of 30 capsules. Every filter element is checked for cut-off size before dispatch and is guaranteed to the specification.

The main by-pass filter unit is illustrated in Fig 4 and is designed to pass 30 lb/sec of carbon dioxide. Eight sintered iron elements are required and the pressure drop over the elements is 6 p.s.i. The elements are hung from a diaphragm plate and are removable if necessary.

A pressure differential indicator is provided to give warning when the build-up of dust on the elements is excessive and the filters will then be shut down for cleaning. The filter elements are relieved of their dust load by reversing the flow of gas through the filter vessel. This is accomplished by a blast of gas of 2-3 seconds duration, which has the effect of blasting the particles of dust from the pores of the sintered metal. The dust is then given time to settle with the inlet and outlet valves closed. To remove the dust the carbon dioxide is exhausted to atmosphere via the blow-down plant, the coffin shield is unbolted and the coffin containing the dust removed and replaced with a clean coffin. The blow-down filters are similar in design except that blow-back is accomplished by compressed air. For the safety relief valves the filter units are connected directly to the relief valves; the elements are of sintered bronze with a 3-micron characteristic. Should the filter require cleaning the elements are easily removable.

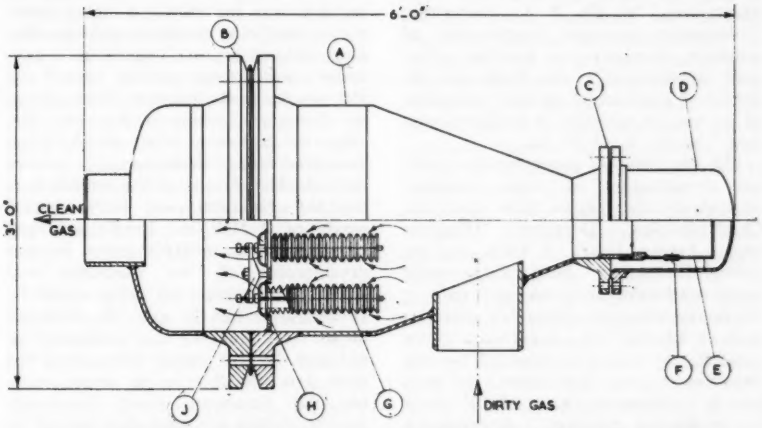


Fig. 4.—Typical by-pass filter unit. 8 filter elements, 30 lb/sec pressure drop 6 p.s.i. Key: A—Body; B—Seal welded flange; C—Coffin retaining flange; D—Coffin shield; E—Coffin; F—Pressure equalizer; G—Filter element; H—Diaphragm; J—Element retaining spider.

The sintered metal filter has two very important advantages over any other type of filter. It has a positive cut-off, so that it can be guaranteed that all particles down to 5 or 2½ microns respectively are retained and costing has shown that the capital outlay of any comparable type of filter handling the same volume of gas is approximately 50% greater.

Acknowledgments

The author wishes to thank Mr. F. Fuell, Chief Designer, Hydraulics Division, Fairey Aviation, and his staff for their co-operation in preparing this paper, which is published by permission of the Managing Director of Atomic Power Constructions Limited.

Large Radiation Sources in Industry

By R. ROBERTS, Ph.D.
(*U.K.A.E.A., Wantage Radiation Laboratory*)

A conference on the Use of Large Radiation Sources in Industry—and especially chemical processing by this means—was held in Warsaw from September 8 to 12, 1959. The first international conference to be arranged by IAEA, it was attended by 200 scientists from 26 different countries.

THE proceedings of the conference were divided into three main groups. (a) A description of large irradiation units together with papers on the types of source material to be employed. This group of papers also included a discussion on the use of fission fragments as radiation sources. (b) Uses of radiation in the chemical industry. (c) General applications of radiation in industry. At the end of the third group of papers there was a general discussion on the economies of radiation processing. Four survey papers were also given. These were "Recent trends in polymer radiation work," by Professor A. Charlesby; "The United States industrial radiation programme," by Dr. P. C. Aebersold; "Elementary processes characteristic of radiation chemistry and possible industrial applications," by Professor M. Burton; "The current concept and status of the uses of radiation in food preservation," by Dr. R. G. H. Siu.

The first group of papers on the design and construction of large radiation sources included papers from Australia, Czechoslovakia, Denmark, Hungary, Japan, France, U.S.A., U.S.S.R. and the United Kingdom. Most of the really large irradiation units are still only in the design stage and only a few countries such as France, U.K., Australia and the U.S.S.R., are actually engaged on the construction of irradiation facilities having activities in excess of 10^5 curies for production purposes. Construction of the American Hi-Rad facility will start later this year and be complete by the beginning of 1961.

Many of the basic designs of the large irradiation units are similar, the source being stored in a water pit contained within a concrete shield. For purposes of irradiation, the source is lifted from the pit into a position in which it is surrounded by various conveyors. The sources are of various types, the most popular being a plaque. A number of small laboratory sources in which lead shielding is used were described but no new concepts emerged in sources of this type. During the discussion it was stated that in addition to the sources of 30,000 curies now under construction at Lyon and the pilot plant sources of 150,000 curies each at Wantage Radiation Laboratory, in the U.K., a source of 150,000 curies was presently being installed in Australia for the purpose of sterilizing goat hair. Mr. Bibergal of the Soviet Union stated that they were constructing, near Moscow, a 50,000 curie plant for irradiating potatoes. Russian scientists have not yet received a general mandate from their health authorities for the sale of irradiated potatoes on the open market. The representative of the Socony Mobil Company of the U.S.A., also stated that a 5 MW reactor constructed by a group of companies connected with the oil, rubber, explosive and tobacco industries would be ready for use by the end of October.

Radiation Sources

In a discussion on possible sources of radiation, Dr. Silverman of the U.S.A., mentioned the use of β emitters such as Sr^{90}. No β source, satisfactory for long-term use has yet been developed. An interesting new concept from the U.S.S.R. was the use of a liquid metal circuit containing an indium-gallium alloy as a radiation source. This circuit is now under construction—making use of the IRT reactor at the Institute of Physics of the Georgia Academy of Sciences. The alloy which has a M.P. of 16.5°C is circulated using electromagnetic pumps through the reflector of the reactor to a shielded irradiation unit. For a reactor power of 2 MW, the irradiator would have an activity of 20,000 curies. Further development of the technique was envisaged in which the alloy would be circulated through the core. No estimates of the economics of the production of radiation by this means were given but from data available in the design study for the American Food Irradiation reactor, it does not seem that the use of liquid metal will be a particularly cheap source of radiation.

The exceedingly low cost of fission fragments as radiation sources was stressed in papers by Coekelbergs (Belgium), Dawson (U.K.), and Harteck (U.S.A.). Professor Harteck felt that the problem of the separation of the fission fragments from the reaction products had been largely overcome by the use of uranium dissolved in glass fibres but other workers were not so sure. Professor Coekelbergs stated that the problem of using the chemical energy from fission reactions was still in the research stage and that much further work still remained to be done.

The section on the use of radiation in the chemical industry was opened with a review by Professor Charlesby on recent work in radiation effects in polymer chemistry. He reviewed briefly work on the effects of radiation on plastics and elastomers, radiation-initiated polymerization and graft copolymerization. He mentioned the curing of resins by radiation and the possibility of using the memory effect of polyethylene to advantage. The recent work on the initiation of ionic polymerization by radiation was said to open up an entirely new field for radiation processing.

In the section dealing with radiation effects on plastics and elastomers, most of the papers presented were concerned with the detailed radiation chemistry of the changes taking place when these materials are irradiated. The use of multifunctional monomers to aid crosslinking was described in a paper by Dr. Pinner (U.K.), read by Professor Charlesby (U.K.). The use of this technique was stated to materially lower the dose required for crosslinking. Professor Oster (U.S.A.) pointed out that, as long as thin films were used, many of the effects of high energy radiation on polyethylene could be duplicated by ultraviolet light used in the presence of a sensitizer. This was, of course, very much cheaper. He also observed that when crosslinking of fibres is carried out by conventional means, the crosslinking agent often causes swelling of the fibre so that the orientation of the macromolecules is disrupted. He felt that if fibres could be crosslinked by radiation, the original orientation would be maintained and one would expect a fibre possessing a superior tensile strength. A paper was read by Kuzminski, Nikitin and Oksentievich of the U.S.S.R. on the use of ionizing radiation for the vulcanization of silicone rubber. By irradiation of polydimethyl siloxane rubbers mixed with various fillers such as titania, silica flour and carbon black, products exhibiting superior thermal ageing characteristics could be obtained.

Grafting Polymers

Many of the papers in the next session were devoted to the well-known technique of the radiation induced grafting of polymers and there were only a few studies on radiation-initiated polymerization as such. A paper from the U.S.S.R. by Medvedev, Abkin and Khomilovsky on ethelyene polymerization by radiation, mentioned the use of solution polymerization to increase the rate of reaction. In solutions of organic solvents such as alcohols, acetone and aliphatic hydrocarbons, it was shown that, at 50 atm pressure and room temperatures, the rate of the solution polymerization was 10 to 15 times higher than that obtained in the gas phase. The physical properties of the polymers obtained in solution were not as good as those from gas phase polymerization, the latter polymers being characterized by increased density and crystallization. The

material was, in fact, very similar to that obtained by low pressure processes using organo-metallic catalysts. The partial reduction in the solubility of silicone polymers by the grafting of acrylonitrile chains was described in a paper by Dalton and Roberts from the U.K.

Before the section dealing with general chemical reactions induced by radiation, Dr. P. Aebersold reviewed the current United States industrial radiation programme. Radiation is now being used industrially in the United States for the irradiation of polyethylene and for the sterilization of sutures. The United States was approaching the problem of using radiation industrially in five main areas. 1. Applied radiation process research. 2. Investigation of intermediates in radiation-initiated processes in fundamental chemistry. 3. Development of the use of radiation as an engineering operation. 4. Research in source technology. 5. Development of nuclear reactors as sources of ionizing radiation. Among projects in applied radiation process research, he described work on the nitrogen fixation process using fission fragments and also on the nitration of cyclohesoane. Work on the effect of radiation on platinum and iron catalysts was being carried out in several universities and private companies.

Chemonuclear Reactor

Work is to start this year on a high level radiation development laboratory which would initially have a source of 200,000 curies. This would later be built up to 0.5 megacuries. There is great interest in the United States in the chemonuclear reactor, i.e., a reactor in which chemical reactions are carried out in addition to its use as a power producer. A 20 MW organic reactor could process 10^6 million megarad lb of fluidized material per hour. In conclusion he felt that with the eventual development of less expensive sources of radiation including accelerating machines, cobalt-60 and nuclear reactors, it will become feasible to think of radiation as being competitive with heat, pressure and electricity for the chemical industry.

The first papers on general chemical reactions initiated by radiation dealt with the oxidation of hydrocarbons. Work on the oxidation of cumene to form hydroperoxides by Durup and Magat (France) was described by Dr. Puig (France). Similar work on the oxidation of cyclohexene and di-isobutylene was described by Montarnal and Brun (France). In both these papers the emphasis was on the fundamental reaction kinetics of the process. These appeared to parallel closely those already determined for oxidation reactions using other methods of catalysis. The work of Borelko, Kartashova, Komarov and Proskkurnin (U.S.S.R.) on the radiation oxidation of benzene in aqueous solution was described by Prof. Bach (U.S.S.R.). At elevated temperatures the oxidation of benzene takes place by a chain process and a phenol yield of 30-50 molecules per 100 eV of absorbed radiation energy was observed. In addition to phenol, diphenyl and various acids are formed.

The use of radiation increases not only the chain length but also raises the initiation rate. A proposed flow sheet for a pilot plant was shown but it was stated that the plant had not yet been built. Work on the radiation-initiated oxidation of hydrocarbons using a small pilot plant was described by Joanid, Dragut and Drimus from Rumania. The principal products appear to be acidic in nature.

Radiation-initiated halogenation was discussed in papers from France, U.S.A. and U.K. The papers from U.S.A. and U.K. were largely devoted to questioning earlier results on radiation-induced halogenation in which it had been claimed that high energy radiation would give products different from those obtained when ultraviolet light was used. No evidence for such differences was found and it was shown that the discrepancies were due to differences in the physical conditions used for the experiments.

Work on the effects of radiation on heterogeneous catalysts was described in papers by Turkevich and Taylor from the U.S.A. In his paper on radiation damage and catalysis Professor Turkevich described fundamental work which is being carried out on the effect of radiation on zinc sulphide while Dr. Taylor described the dramatic increase in the activity of an amorphous silica catalyst for the hydrogen deuterium exchange reaction brought about by subjecting it to γ radiation.

The prospects for the industrial use of irradiation in the thermal cracking of hydrocarbons was discussed in a paper by Topeliev (U.S.S.R.) *et al.*, read by Professor N. Bach (U.S.S.R.). It was stated that at temperatures of the order of 200-300°C, cracking yields of the order of 10^3 molecules/100 eV could be obtained. By proper choice of dose rate, dose and temperature it had been found possible to increase considerably the yield of hydrocarbons. A considerable amount of molecular hydrogen was also produced. Similar results for n butane were described by Turner (U.K.) who found that the radiation assisted cracking of n butane was low at temperatures below 250°C but it increased above 300°C reaching values of $G(-C_4H_{10})$ of 10^3 at 450°C. As the temperature approached that at which ordinary thermal cracking set in, the products became more akin with those obtained thermally.

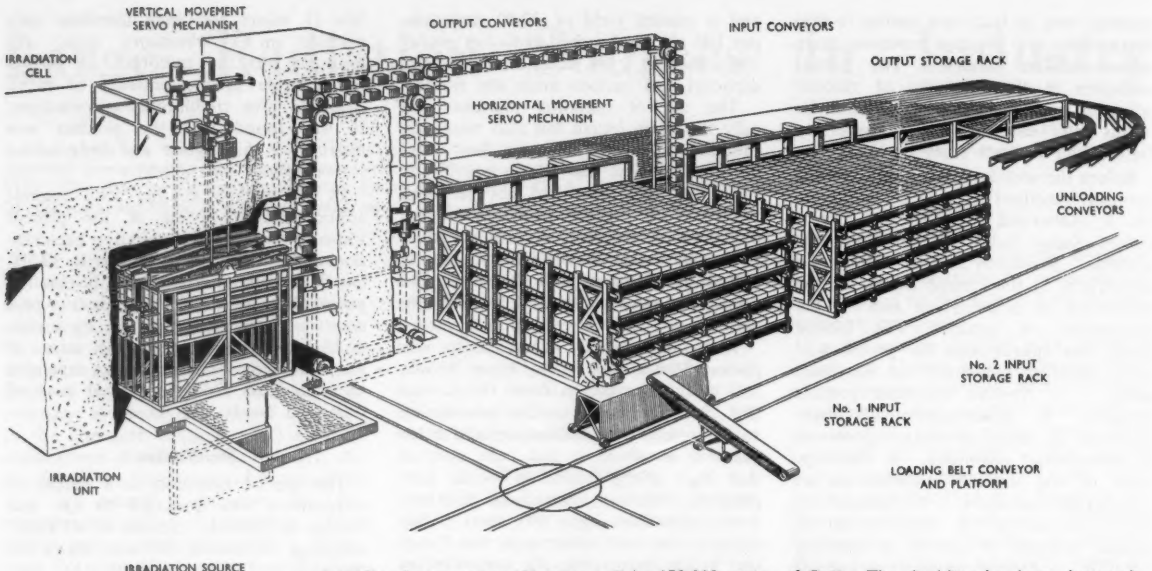
A series of interesting new syntheses was described by Dr. Henglein (Germany). These were the dichlorophosphines and nitroso compounds obtained by the irradiation of mixtures of phosphorous trichloride and hydrocarbons and by irradiation of chlorinated compounds in the presence of the radical scavenger nitric oxide. He stressed that the processes were ones of low G values and were therefore only suitable on a laboratory scale. An example was the radiolysis of carbon tetrachloride in the presence of nitric oxide to give trichloronitroso methane. It was found that the product was obtained in high yield and little or no side reactions took place.

In the section dealing with general applications, a review of the present status of work on the radiation preservation of food was given by Dr. R. G. H. Siu (U.S.A.) who stressed the fascinating potentialities of the food irradiation process. These included aid to undernourished people, decreased cost of merchandizing certain foods, expanded trade in fresh fruits, improved taste of processed foods and so on.

Sterilization

The use of radiation as a means of sterilization was discussed by Dr. van Winkle of Ethicon. Sutures of all kinds, dressings, ointments, enzymes, fluids for injection and other substances are now being satisfactorily sterilized by radiation. Mr. Jefferson (U.K.) said that in the U.K. one company had already placed a radiation sterilized catheter on the market and its use had resulted in a marked reduction in the number of cases of subsequent bladder infection. The cost of the sterilization treatment was a negligible fraction of the catheter cost.

The last phase of the conference was marked by a short discussion on the economics of radiation processing. Michaelis (U.S.A.), described the main conclusions of the major study recently undertaken by the U.S.AEC on the costs of high energy radiation processing. Cost factors were analysed and quantitative data presented on the capital, installation, operating and maintenance costs of various sources such as Co^{60}, Cs^{137}, and electron accelerators. It was concluded that there was a good chance of radiation output costs in the future of 10 cents per kWh, whereas costs at the moment are of the order $1-10. Estimates of the cost of irradiating polyethylene were given by Dr. Ranftl (U.S.A.), of General Electric, while Professor Okamura (Japan) gave details of the estimated costs of the radiation-induced chlorination of polystyrene. These, he claimed to be lower than those hitherto estimated. During the discussion there were the inevitable comparisons of the cost of electron accelerators and radioisotope sources, many of the assumptions taken in cost estimates being questioned. It was apparent that no detailed costing of the large radiation units has yet been released. Many speakers felt, however, that the costs of radioisotopes in megacurie quantities were likely to decrease considerably over the next few years. The discussion also revealed some uncertainty regarding the maintenance costs for electron accelerators; some speakers suggested that a minimum of two machines was required for each installation.



Initially, the source at Wantage will be 150,000 curies of Co^{60}. The shielding has been designed for up to 500,000 curies. A second cell (to the left) has been built for a duplicate installation should this prove desirable.

Package Irradiation Plant

ONE of the world's first large-source irradiation facilities is about to go into operation at the Wantage Radiation Laboratories, a few miles from AERE, Harwell. The plant—built for the Technological Irradiation Group of the Isotope Research Division by the Owen Organization—comprises a 150,000 curie source of cobalt^{60} with an automatic conveyor line. Initially, the throughput will be 7 megarad-tons per day: in 24 hours 3 tons of medical products or animal fibres could be sterilized at a dosage of 2½M rad. At a future date the source may be increased to 500,000 curies.

With a view to making use of the large quantities of isotopes that will become available in the years ahead, the Technological Irradiation Group has been investigating the commercial possibilities of large-source radiation processing for some time.

Following an initial study of the problem a scheme was evolved based on a large Co^{60} source: unit-size packages were to be moved past the source on a continuous conveyor with facilities for stopping radiation immediately in event of a conveyor breakdown. Because of the possibility of commercial exploitation and subsequent control by semi-skilled operators the plant also had to incorporate interlocks to prevent entry to the shielded area unless the source had been dumped.

Taking account of all these factors, the final design called for a source of up to 500,000 curies with a water storage pond below for ease of dumping and an automatically indexing continuous conveyor system with two lines to accommodate different irradiation times.

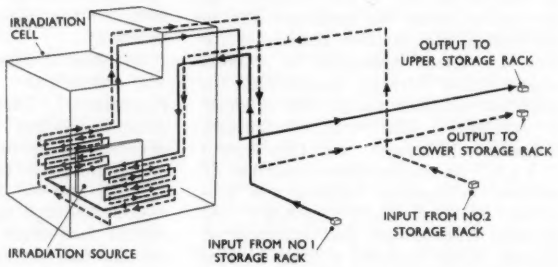
The new irradiation building at Wantage occupies an area of 10,000 sq ft, 10% of which is taken up by the cell and conveyors, the remainder being intended for storage of material both before and after processing. The plant is based on a unit package size of approximately 1 cu ft. As can be seen from the accompanying illustration, there are two input storage units, two input Paternoster elevator conveyors, a "shuffling" device for controlling the presentation of packages to the source, two output Paternoster conveyors and a large output storage rack.

A variable flow rate has been arranged so that the period in the cell can be anything from a few minutes to several hours. The shuffling device, which is hydraulically controlled, transfers both lines of packages from the input conveyors along five horizontal levels in sequence on each side of the source. In this way every package on a particular input line receives exactly the same amount of radiation. Furthermore, the presentation of the package to the source is arranged to ensure that the whole of the package receives the same amount of exposure.

Initially, the plant at Wantage will concentrate on the sterilization of medical products such as catheters.

A second irradiation plant—based on a design developed by the Technological Irradiation Group—is nearing completion at Melbourne, Australia. It will be operated by the Westminster Carpet Company for the sterilization of goats' hair used for making carpets.

Overall responsibility for construction of the irradiation plant was assigned to the Owen Organisation. Three member companies involved were Electro Hydraulics at Warrington (control mechanisms, hydraulic drives and pumping sets), Rubery Owen Research and Development Group at Darlaston (conveyors and storage rack) and Salopian Engineers of Prees (structural work).


IRRADIATION CELL
OUTPUT TO UPPER STORAGE RACK
OUTPUT TO LOWER STORAGE RACK
INPUT FROM NO.2 STORAGE RACK
IRRADIATION SOURCE
INPUT FROM NO 1 STORAGE RACK

Flow diagram for the irradiation cell and conveyor system.

Westinghouse Proposals

U.S. Utility Companies Offered 3 Nuclear Variations

THREE nuclear power-plant concepts, considered by Westinghouse to be logical alternatives for electrical utility companies to adopt in their programmes of nuclear power production, have been announced. It has been possible for Westinghouse to guarantee plant output, overall plant costs and fuel life in two of these projects. Water reactors are considered by the company to have the most promise of achieving competitive nuclear power, the soonest, preferably with superheat, and the most immediate proposal to cover this is the Combination Plant.

Combination Plant

Called combination because it uses both nuclear and fossil fuel, the plant was designed around the requirements of modern turbine and steam conditions, the reactor and superheat system being designed to satisfy these conditions. The turbine is rated at 225 MW and the steam inlet conditions at the first stage are 1,800 p.s.i. at 1,000°F with reheat temperatures of 1,000°F. The steam conditions are achieved by the use of a direct cycle system followed by a fossil-fired superheater as the next stage. In addition to superheating the steam before it goes to the first stage of the turbine, the superheater is used to reheat steam to 1,000°F before it is fed back into the second section of the turbine.

Water is circulated through the reactor core where some boiling takes place at 2,115 p.s.i., by canned motor pumps.

The water is separated from the steam in a steam separating drum located in the loop between the reactor and the superheater and is returned to the reactor cycle. Steam fed through the superheater passes to the first section of the turbine at 1,800 p.s.i. and 1,000°F. After passing through both stages of the turbine the steam is condensed and returned to the reactor. Statistics of the plant are: reactor vessel: 34 ft high, 9¼ ft inside diameter with 8-in.-thick walls of carbon steel clad with a ¼-in. thickness of stainless steel. Fuel is about 26½ tons of uranium pellets enriched to about 2%. The superheater with auxiliary equipment is 146 ft high and 76 by 65 ft in rectangular dimensions. It is fuelled with either oil, gas or coal. Total heat rate of the plant is 9,040 B.t.u./kWh net, with the reactor providing about 300 MW (thermal) and the superheat about 220 MW (thermal) giving a combined 225 MW electric output.

The plant, construction of which could begin immediately, is credited with producing electric power for 7.3 mill/kWh. The cost break-down is as follows: 3.4 mills in capital investment; 2.7 mills for fuel; 0.5 mills for indirect costs and 0.7 mills for operation and maintenance.

Integral Boiling and Superheat Reactor

The second plant proposed is an all-nuclear type with integral superheating. In this plant the water is both boiled and then superheated within the reactor core, no separate unit for superheating being required. The reactor is water/steam cooled and graphite moderated and is designed on the pressure tube principle. The fuel is in the form of rod clusters suspended in the tubes and the core is surrounded by a carbon-steel vessel. During operation, circulating water enters the centre region boiling tubes and is rapidly heated as it passes through the fuel region. The heated mixture of steam and water then moves up to one of four steam drums located above the reactor, separated, and the water then returns to the bottom of the boiling tubes in the centre region of the reactor whilst the steam flows into the upper end of the superheating tubes located in the perimeter area of the core. The superheated steam collects in a header and then flows directly to the turbine. Helium at a pressure of 100 p.s.i. blankets the graphite moderator in the containing vessel. The helium controls the heat transfer from the graphite moderator to the pressure tubes and at the same time maintains the graphite temperature within safe operational limits.

Prototype plant statistics of this concept are: Electrical output, 20 MW. Graphite block, 11 ft in diameter and 14 ft high. 56 pressure tubes in the centre boiling area and 24 tubes in the superheat area. The tubes are 2.7 in. in diameter and there are 19 fuel rods 10 ft by ½ in. diameter. Containing vessel is 23 ft high and 12½ ft in diameter and is made of carbon-steel ½ in. thick. The turbine operates at a steam pressure of 850 p.s.i. and 900° F.

It is considered that a full-scale plant (200 MW) could be in operation by 1975, but a number of problems remain to be solved, particularly as regards control.

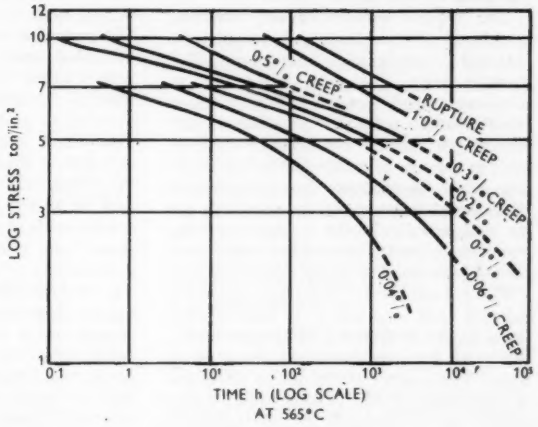
330 MW Closed-cycle Plant

The 330 MW closed-cycle, water-moderated plant is based on the philosophy that there is economy in large reactors and that the closed cycle is the most proved type to date. The system uses both a primary and secondary loop. The primary loop circulates pressurized water through the reactor and a heat exchanger where the heat is transferred to a secondary loop and produces steam which is piped to the turbine. The condenser and other secondary equipment are all of conventional design. Fuel is in the form of uranium oxide pellets, clad in either stainless steel or Zircaloy-2, and, for more uniform heating and better fuel economy, is loaded in three levels of enrichment. These comprise one central and two annular zones, the inner enriched to about 2.1%, the second to 2.6% and the outer to about 2.9%. After the primary loop water passes through the reactor it flows to one of five steam generators, each of which produces 900,000 lb/h of dry saturated steam.

Statistics are: Reactor vessel weighs 300 tons and is 41 ft high and a little less than 12 ft inside diameter. Walls are carbon steel about 10 in. thick with an inner cladding of 1¼-in. stainless steel. Within the guarantees offered, the estimates of the power cost break-down are: Capital expenditure, 3.3 mills; fuel, 3.0 mills, and operation and maintenance 0.5 mills, indirect costs, 0.5 mills, making a total of 7.3 mill/kWh.

Steel—Erratum to *Nuclear Engng.*, July-Sept. Data Sheet No. 14

Nuclear Engineering Data Sheet No. 14 on Steel (July/August/September, 1959) contained an incorrect series of creep design curves. The correct curves for Fig. 2(b) are reproduced on the right.



Technical Papers

The Prospect for a Nuclear-powered Dry Cargo Liner with Particular Reference to the Organic Moderated Reactor.*

By E. C. B. CORLETT and E. P. HAWTHORNE

THE feasibility study conducted jointly by Burness Corlett and Partners and Hawker Siddeley Nuclear Power deals with the application of nuclear power propulsion in cargo liners and, to quote the authors, their study has been progressed to the point where "we feel with some confidence that a ship of the type described could be built almost immediately, if the initial development finance were available."

Design and construction of the proposed nuclear ship (or family of ships) is based on the U.S. oil-fired Mariner class of cargo liner and has been planned for use on the U.K.-Australia routes carrying refrigerated foodstuff and thus benefiting from the comparatively high freight rates applicable in that trade. Calculations of the economics indicate that the nuclear ships are very nearly as attractive commercially as conventional ships and show a positive profit margin in every case. However, this conclusion presupposes that capital investment is restricted to the actual building cost of the vessels and all development expenditure has been absorbed or written off previously.

The main data of the nuclear ship considered more specifically (compared with those of the corresponding Mariner model) are given as follows: length, 528 ft 6 in. (ditto); breadth, 84 ft (76 ft); depth, 53 ft 6 in. (44 ft 6 in.); draught, 32 ft 9 in. (31 ft 7 in.); displacement, 25,700 tons (22,560 tons); service speed, 19.8 knots (ditto); and continuous shaft horse-power, 19,450 s.h.p. (17,900 s.h.p.). The nuclear version has been designed for the same speed, same length and same total deadweight as its Mariner counterpart, and the actual differences in the above data derive from the absence of fuel oil carried in the conventional ship, and the provision of additional space to compensate for the area actually occupied by the reactor room.

The reactor system chosen employs enriched UO_2 as fuel and an organic material (terphenyl, "Santowax R" manufactured in this country) as moderator and coolant. The authors justify their choice by pointing at the advantages offered by organic cooling, such as the use of mild—instead of stainless—steel throughout the system, low operational pressure levels and little or no radioactivity in the coolant circuits, but it is conceded that other types may be competitive after further development.

The reactor room, 19 ft from the ship's sides, is 45 ft long and 45 ft wide, placed immediately in front of the engine room, the latter being in the conventional position. The reactor containment envelope is 3 ft clear of the reactor room bulkheads, has a diameter of 38 ft and a height of 38 ft, and is made from 1¼-in. thick mild steel plate. Integral with it is the secondary shield, consisting of 3-in. thick lead slabs bolted to the casing. The envelope is designed for a pressure of 105 p.s.i.g., which compares with 70 p.s.i.g. expected under the worst accident conditions. The reactor with its primary biological shield is situated centrally within the containment envelope. The primary shield is of a composite design, made up of steel, lead and layers of water, holding about 134 tons of the latter. The control rods are inserted from below the core and, under scram conditions, are sprung into position automatically. The fuelling machine, above the core, discharges spent fuel elements, through an opening in the reactor vessel head, into coffins which can be handled by dockside cranes.

SPECIFICATION OF REACTOR PLANT

Core	
Maximum heat output (including normal overload margin)	64MW
Core height	5.0 ft
Nominal core diameter	5.75 ft
Number of fuel channels	290
Number of fuel rods per channel	19
Fuel	UO_2
Initial enrichment	1.6 to 1.8%
Canning	Stainless steel
Weight of uranium	7.9 tonnes
Average rating	8.1 MW/tonne
Average burn-up	10,000 MW/tonne
Number of control rods	19
Primary Circuit	
Composition of coolant/moderator	Terphenyl+30% polymer
Temperature at reactor inlet	295° C
Temperature at reactor outlet	341° C
Maximum operating pressure	90 p.s.i.g.
Maximum coolant flow	1,294 lb/sec
Total pumping power	322 b.h.p.
Make-up rate of terphenyl	1,950 lb/d at full power
Number of primary circuits	2
Secondary Circuit	
Total evaporation at N.S.P.	196,910 lb/h
Steam flow to main engines at N.S.P.	160,380 lb/h
Superheater outlet conditions	630 p.s.i.g./620° F
Final feed temperature	320° F

The two main heat exchange circuits are completely separate; each comprises superheater and evaporator sections of shell-and-tube design with the terphenyl on the shell side, and a steam separator. The propulsion machinery is largely conventional and consists of an impulse high-pressure turbine and a single flow impulse reaction low-pressure turbine, coupled to a double reduction gearbox. The steam leaving the former is 7.7% wet and is dried to 1% before entering the latter, where it emerges with a wetness of 11.3% at 28.5 in. Hg. A dump condenser is provided to deal with excess steam, as may be generated during manœuvring of the ship or while in port. An oil-fired boiler provides the supply for the ship's services during the starting period while the main turbines are developing 20% of their normal rated power and, alternatively, can be used in case of breakdown for propelling the ship at a speed of up to 12 knots.

The moderator/coolant enters and leaves the reactor at the top, to ensure that the core is submerged under all, including accident, conditions. The reactor is designed to work safely at a permanent list of 20°, and two emergency cooling circuits, effecting cooling by convection, would still operate at a heel of 90°.

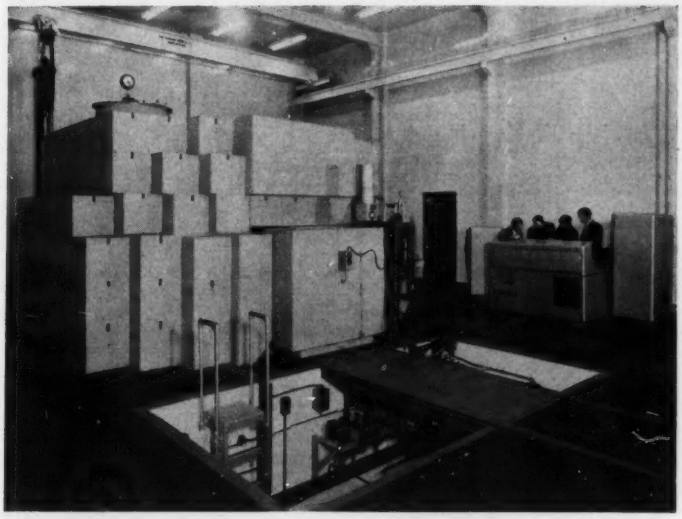
Under irradiation, the organic coolant will form polymers and hydrogen/methane, present in a dissolved state in the liquid. The excess polymer is currently removed by distillation and a degassing process deals with the gaseous decomposition products.

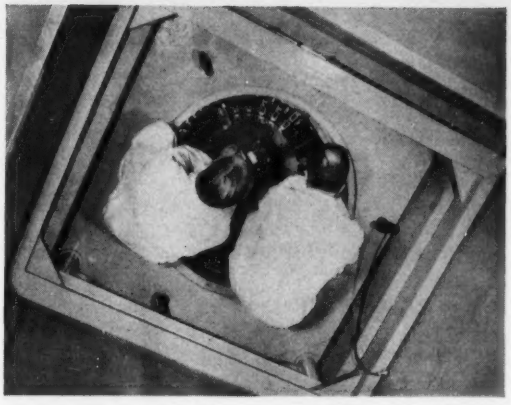
A limiting property of terphenyl is its high solidification point, 280°F. This, therefore, constitutes the minimum temperature permissible in practice for all circuits carrying, or in contact with, terphenyl. On the other hand, supplies of terphenyl can be taken on board in solid form, facilitating storage in quantities sufficient to last for a round trip from the U.K. to any part of the world. For use, the terphenyl is melted down and fed to the working storage. Another property to be watched is that terphenyl will burn under certain conditions; its flashpoint is 194°C, its free burning point 220°C, and its spontaneous ignition temperature over 500°C. Accordingly stores are kept under a nitrogen blanket. Experiments, however, have established that, at a temperature of 350°C (which is above normal operating temperature) combustion cannot be initiated as long as the oxygen content of the ambient atmosphere is below 15%. Thus, it is stipulated that the containment vessel atmosphere and ambient atmosphere for all relevant coolant circuits must be kept at an oxygen content not exceeding 14%.

The reactor is brought from subcritical to hot standby in 2 hours; its power can be increased from 15% to 100% in 15 minutes. To control equilibrium xenon poisoning, it is suggested to build 2.2% excess activity into the core. The average thermal flux equals 0.9×10^{13} n/cm² sec.

The reactor has an effective negative temperature coefficient of reactivity. This greatly facilitates operational control and offers the possibility of holding both the reactor coolant inlet and outlet temperatures constant during load changes over a given load range, i.e., basically, operational controls are designed to effect a change in reactor power by adjustment of the flow of the coolant.

* Paper delivered under the auspices of the Joint Panel on Nuclear Marine Propulsion to the Institution of Naval Architects, 10 Upper Belgrave Street, London, S.W.1, on October 7, 1959.





The JASON research reactor of Hawker Siddeley Nuclear Power being checked for operating characteristics and stability during the successful start-up period. (Below) Scientists removing fuel boxes after the first run. JASON went critical on September 30, just seven months after construction began.

World News

International

VOLUNTARY CONTRIBUTIONS totalling $915,133 have been made by member states of the IAEA to the General Fund. The U.S. are the largest contributors with $500,000 and a pledge to match dollar for dollar the amount reached above $1 million. The U.K. have pledged $125,000.

UNANIMOUS APPROVAL was given to a draft resolution of the Programme, Technical and Budget Committee to accelerate the IAEA's programme for assistance to the less developed countries in the production of nuclear power.

FIVE ADDITIONAL COUNTRIES have been selected to serve a two-year term on the IAEA Board of Governors. They are Bulgaria, Ceylon, Mexico, Philippines and Spain.

UNANIMOUS APPROVAL to the mandate for a temporary Committee for the European University has been given by the Euratom Council of Ministers. The committee will present a report on the institution of a council and a list of faculties for the University by the end of the year.

FOURTH PRELIMINARY assistance mission of the IAEA left on October 12 for a visit to Afghanistan, Iran, Iraq, Turkey and Yugoslavia. Dr. H. Smith, head of the IAEA Division of Isotopes, was in charge.

A MOVE TOWARDS a co-ordinated energy policy for Europe has been made in agreement being reached on proposals by the European Coal and Steel Community, Euratom and the European Economic Community.

A SYMPOSIUM on the metrology of radioisotopes was held in Vienna by the IAEA from October 14 to 16. Thirty-five papers were presented.

United Kingdom

SOMERSET COUNTY COUNCIL have approved a scheme designed to harmonize Hinkley Point nuclear power station with the landscape by the use of soft blue, grey and green colours. The scheme has been prepared by the CEGB architectural consultant, Mr. F. Gibberd.

THIRD CONFERENCE on nuclear energy risks insurance ended in London on October 15 with agreement on major technical matters being reached by 13 European national insurance pools. The conference was arranged by the British Insurance (Atomic Energy) Committee.

THIRD COURSE on the control and instrumentation of reactors, open to overseas students as well as British, will be held at Durley Hall, Bournemouth, from February 1 to 12, 1960, by the AEA. Visits to zero energy and high flux research reactors will be part of the course.

SUBSTANTIAL INCREASES in wages and an additional week's holiday have been called for by the Trade Union Side at a meeting of the General Purposes Committee of the National Joint Industrial Council for the AEA. The Authority have undertaken to consider the claims.

THE ISOTOPE SCHOOL has been moved to the Wantage Radiation Laboratory after eight years' operation at Harwell. It is now housed in new buildings especially designed for the purpose, while at Harwell it occupied converted buildings.

Members of the Japanese Core Structure Study Group who visited the G.E.C. structural engineering laboratory at Erith during discussions on the new earth-quake proof graphite core for the nuclear power station which G.E.C. will build near Tokyo.

Australia

THE NEW ARRANGEMENT, under which Australian producers of uranium may export to countries other than the U.K. and U.S.A., is similar to the Canadian one. A total of 2,500 lb may be exported to any one country with individual sales limited to 250 lb. First shipment of this nature is from Mary Kathleen Uranium to Japan.

REWARD PAYMENTS for uranium discoveries totalling £A8,750 have been announced by the Minister for National Development. United Uranium receive £A8,000 for the discoveries at El Sharana in the South Alligator River area and R. T. Norris and Partners, £A750 for a discovery at Pandanus Creek. Both finds are in the Northern Territory.

Austria

A NEW AGREEMENT for the peaceful uses of nuclear energy has been signed with the U.S.A. Under it the total amount of U^{235} transferable to Austria will be raised from 6 to 50 kg and the U.S. are to supply uranium enriched up to 90% for use in special research or material testing reactors.

Belgium

PNEUMATIC TESTING of the protective steel containment shields of the BR2 and BR3 reactors at the nuclear research centre at Mol has been completed.

Canada

A FRAMEWORK AGREEMENT has been signed with Euratom for co-operation in the peaceful uses of nuclear energy and a technical agreement has been signed by the president of Atomic Energy of Canada. The technical agreement provides for a joint research programme on heavy-water moderated reactors. Each party will set aside $5 million for this programme over a period of five years.

FOREIGN ENGINEERS and scientists as well as Canadian may apply for admission to the Chalk River Reactor School which begins classes on February 1, 1960. The courses last 12 weeks and will have special emphasis on reactors moderated with heavy water and natural uranium fuelled.

NUCLEAR EXPLOSIONS under the Alberta oil sands will not take place as planned in either February or March, 1960. The plans have been postponed indefinitely.

MANITOBA is to be the centre of a new nuclear research station to be built by Atomic Energy of Canada. It is expected that OCDRE, the organic-cooled, heavy-water moderated and natural uranium fuelled reactor project, will be housed in the centre.

Germany

A NEUTRON DIFFRACTION PLANT is to be built for the nuclear research centre at Garching of the Institute for Applied Physics of the Technical University of Munich. The plant has been designed by the university in co-operation with the Augsburg works of MAN who will build the plant.

A NUMBER of West German organizations have formed an Atomic Forum with headquarters in Dusseldorf. Professor K. Winnacker, director of I.G. Farben, chemical works, has been elected president.

THE SOCIETY for the Application of Nuclear Power to Shipping has secured an option on a 15,600-ton tanker with the view to building a reactor to power the vessel. Design work on the reactor and propulsion unit will be done by Interatom.

Greenland

URANIUM ORE DEPOSITS in promising quantities have been found in areas over 150 to 200 miles of the coastal region of the south-west. It has been estimated that each ton of ore contains up to 12 lb uranium.

India

A TRIGA RESEARCH REACTOR, in operation, will be part of the U.S. AEC contribution to the First World Agriculture Fair to be held in New Delhi in December.

PLANT DESIGN is now in hand for the construction of a facility for the treatment of irradiated natural or slightly enriched uranium fuel elements and the extraction of plutonium.

Italy

THE LOAN AGREEMENT between the International Bank for Reconstruction Development and the Fund for the Development of Southern Italy, for the financing of the SENN nuclear power station at Garigliano, has been signed.

TWO PUBLICATIONS, one on the protection against ionizing radiations in industrial work connected with nuclear power production and another on decontamination experiments of liquid waste containing radium and strontium, are available from the Associazione Nazionale Imprese Produttrici e Distributrici di Energia Elettrica.

Japan

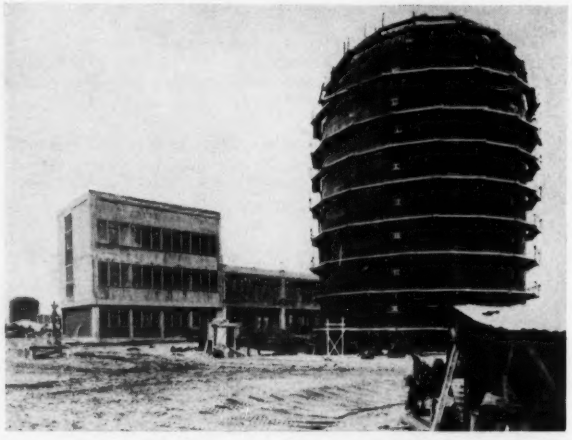
A NUCLEAR SHIP MISSION, consisting of 23 men representing ship building and nuclear power concerns in Japan, is to tour the U.S. this month. Purpose of the visit, arranged by the Atomic Industrial Forum, will be to discuss the problems of and the prospects for, nuclear ship propulsion and its application in Japan.

New Zealand

THE FIRST radio-chemical laboratory has been opened by the chairman of the New Zealand Atomic Energy Authority, Dr. R. W. Harman.

Puerto Rico

BIDS FOR THE CONSTRUCTION of a bio-medical building as part of the Puerto Rico Nuclear Centre have been called for. The building will be located at the new Medical Centre in Rio Piedras.



The BR2 steel containment vessel at the Mol nuclear power centre, Belgium, recently pressure-tested with Atlas Copco compressors.

South Africa

FIRST NUCLEAR research centre is to be located in the Transvaal, according to the Minister of Labour and Mines, Senator J. de Klerk. It will house a 5 MW research reactor, but no decision has yet been taken as to what type of reactor.

Yugoslavia

A DRAFT CONVENTION concerning the responsibilities and liabilities of nuclear-powered vessels was adopted at the 24th conference of the international maritime committee in Belgrade recently. The draft will be submitted to a diplomatic conference of interested Governments not before the end of 1960.

U.S.S.R.

A JOINT VENTURE between the U.S.S.R. and the U.S.A. to solve the problems of thermo-nuclear fusion was one of the subjects for discussion at the meetings between Mr. J. A. McCone, chairman of the U.S.AEC and Prof. V. S. Emelyanov in Moscow. This follows an earlier visit by Prof. Emelyanov to the United States last month when general ways of making available to the rest of the world unclassified research and development programmes was discussed.

A PAPER WAS READ at the Tashkent Conference on the Peaceful Uses of Nuclear Energy, disclosing that the residual pressure in glass vacuum instruments can be reduced by irradiation. This experiment has already been demonstrated in the Nuclear Physics Institute and the Institute of Physical Technology of the Uzbek Academy of Sciences.

ACCORDING TO TASS *Lenin's* running trials in the Baltic have proved successful.

U.S.A.

A LIMITED LICENCE has been issued to Commonwealth Edison by the AEC for the initial fuel loadings of the company's power reactor in Grundy County, Illinois. During operation of the reactor, power level is not to exceed 1 MW.

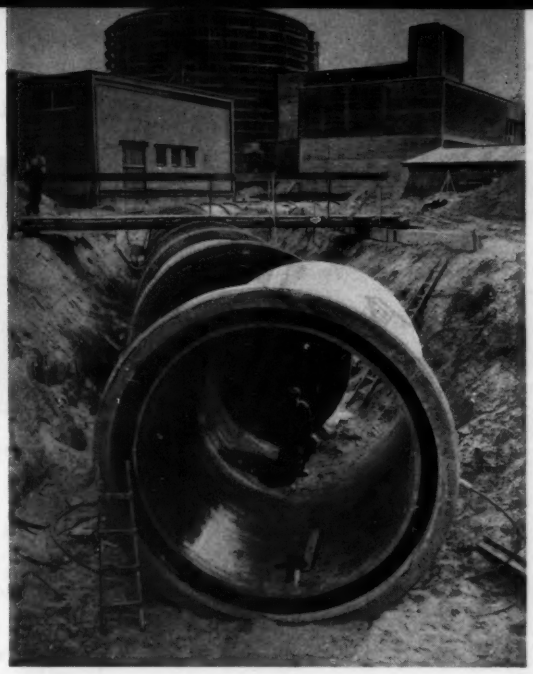
POTENTIAL USE STUDY of nuclear power at remote military installations contract has been awarded to Kaiser Engineers. The contract is worth $515,000 and results have to be submitted by Feb. 1, 1960.

120 DOCUMENTS on the dual-temperature hydrogen sulfide exchange process for the production of heavy water have been made available to the public by the AEC. The information was declassified in December, 1956.

A SURVEY to determine industry's requirements for high-flux irradiation space in test reactors is being conducted by the AEC. The Commission's own needs for irradiation space in the high-flux range are in excess of the capacity of the reactors already built or planned.

SELECTED, as a basis for contract negotiations, is the proposal of Sargent and Lundy for architectural-engineering services for an experimental low-temperature process heat reactor. The reactor would be a pressurized water type, designed to produce approximately 40 MW.

AN ORDER to build the steam generator for the 11.4 MW reactor at Piqua, Ohio, has been received by Alco Products from Atomics International.



Large-diameter pipes being laid at the construction site of the West German nuclear research centre near Karlsruhe. The $20 M project which includes two reactors is expected to be completed by 1965.

AN AUTHORIZATION LICENCE for the disposal of low-level radioactive waste materials in the Pacific Ocean is to be issued by the AEC to California Salvage at San Pedro. Disposal is to be at a minimum depth of 1,000 fathoms.

STANDARDS for the International School of Nuclear Science and Engineering will be raised to a higher professional level and the programme broadened to meet the growing needs for highly advanced and specialized training of scientists and engineers in the nuclear field. The name of the school, located at the Argonne National Laboratory, is to be changed to the International Institute of Nuclear Science and Engineering.

CONCEPTUAL DESIGN of a high-flux reactor will be undertaken by Phillips Petroleum of Oklahoma for the AEC. Purpose of the study is to determine the kind of test reactor that will meet the Commission's needs for neutrons in the high-flux range over and above those which can already be met in reactors built or planned.

SECOND MISSILE firing nuclear powered submarine, the *Patrick Henry*, was launched in September at Groton, Conn. Westinghouse built the pressurized water reactor to power the vessel.

LITHIUM-7 has been made available for sale by the AEC at $120/kg contaminated by only 0.01% Li-6. Price for 99.98% enrichment is $107 and for 99.97%, $100/kg.

UNIVERSITY OF WASHINGTON will receive permission from AEC for construction of a 10 kW light water cooled and moderated reactor as supplied by American Machine and Foundry. The design is the same as the reactor in operation at the University of Florida.

CONSTRUCTION CONTRACT for the experimental gas-cooled reactor (EGCR) at Oak Ridge has been awarded to H. K. Ferguson of Cleveland. The contract is worth $30 million.

OCEAN TRANSPORT of San Francisco is to receive a licence authorizing disposal of packaged low-level radioactive waste materials in the Pacific Ocean at a minimum depth of 1,000 fathoms.

IOWA STATE UNIVERSITY is to be given permission for the operation of a teaching reactor of 10 kW, light-water moderated, graphite reflected and using enriched uranium. American Radiator and Standard Sanitary will build the reactor which costs about $168,000.

Sir Donald Perrott, member of the U.K.AEA (finance and administration) and Mr. T. E. Le Cren, general secretary, Harwell, shown with Dr. L. A. Turner in the experimental boiling water control room at the Argonne National Laboratory.

Personal

Lord Hailsham.

Dr. F. A. Tatford.

Mr. G. G. Ballard.

Mr. O. A. Schulze.

Appointments

Lord Hailsham as Lord Privy Seal with special responsibilities for Atomic Energy.

Dr. F. A. Tatford, director for contracts at the AEA, as president of the Institute of Public Supplies Officers.

Mr. G. G. Ballard as chief engineer of Elliott Nucleonics.

Prof. J. M. Kay, of the Imperial College of Science and Technology has accepted an invitation to be president of the Junior Institution of Engineers.

Sir Roger Makins, who becomes chairman of the AEA on January 1, as chairman of the Ditchley Foundation.

Mr. S. A. Hunwicks as Director of Atomic Weapons (Development) in the Ministry of Supply.

Mr. K. Chatterton, Mr. A. M. Simmers and **Mr. A. Taylor** as special directors of English Steel.

Mr. J. W. Ashley to the board as technical director of Atomic Power Constructions.

Sir Solly Zuckerman as scientific adviser and chairman of the defence research policy committee.

Mr. H. G. Harlow as manager publicity and **Mr. O. Farmer** as group publicity manager of British Thomson-Houston.

Dr. F. Llewellyn Smith and **Mr. I. W. Macdonald** as part-time members of the National Research Development Corporation.

Mr. E. Grundy, Mr. J. Prince and **Mr. O. M. Robson** to the board of Ferranti.

Mr. H. A. Parrott as assistant home sales manager, cable division, **Mr. A. Calby** as manager, London district office of Siemens Edison Swan.

Mr. C. H. Flurscheim of Metropolitan Vickers has been co-opted to serve on the Council of the British Welding Research Association.

Mr. L. R. Mortimer.

Mr. E. A. Smith.

Mr. C. E. Wrangham is now sole managing director of Power-Gas Corporation following the relinquishing of the joint post by **Major W. R. Brown** who continues as chairman.

Mr. R. D. Turner as managing director, **Mr. D. W. Turner** as executive chairman and **Mr. J. T. Lewis** as vice-chairman of Tube Holdings.

Mr. C. Dee to the board of Associated Automation.

Mr. D. C. H. McLean as managing director of Lamson Engineering.

Mr. K. Walker and **Mr. E. Thompson** as joint managing directors of Laycock Engineering.

Mr. E. Sinnott as member of the South Eastern Electricity Board.

Mr. F. V. Thompson as director of personnel, **Mr. J. P. Hourston** as secretary and **Mr. G. V. Tew** as assistant secretary of British Insulated Callender's Cables.

Mr. P. E. Montagnon as manager of the research department of Lightfoot Refrigeration.

Dr. N. Loveless as a consultant to Smiths Aircraft Instruments.

Mr. L. R. Mortimer as south eastern counties representative and **Mr. A. R. Mewitt** as assistant technical sales manager of Kelvin and Hughes.

Mr. A. B. Skevington as branch manager of Philips Electrical.

Mr. C. McInnes as chief project engineer for the new solids handling pump division of Mackay Industrial Equipment.

Mr. R. S. Medlock as president of the Society of Instrument Technology.

Dr. W. D. Scott as managing director of BTR Industries.

Mr. P. H. A. Bowman to the board of Ultra Electric (Holdings).

Mr. W. E. A. Redfearn as chairman of the National Forgemasters' Association.

Mr. G. L. Thompson as managing director of Borax and Chemicals.

Mr. E. A. Smith to the board of Acheson Industries (Europe).

Sir Oswald A. Scott as chairman of Detel Products.

Dr. K. W. Bagnall, Messrs. P. S. Robinson and **M. A. A. Stewart** co-authors of the article on Cylindrical Glove Box with Rotating Table (*Nuclear Engineering*, October issue) are at AERE, Harwell and not with King's College, Newcastle or Boucher and Co., Ltd., as erroneously stated on page 373.

Overseas:

Mr. E. J. Bloch as assistant general manager for manufacturing of the U.S.AEC.

Mr. R. A. Charpie, assistant director of Oak Ridge National Laboratory as secretary of the AEC General Advisory Committee.

Dr. A. J. Stosick as assistant to the director of the John Jay Hopkins Laboratory for Pure and Applied Science.

Mr. J. C. Tourek as vice-president of Vitro Engineering.

Dr. F. Western as acting director of the newly formed office of health and safety of the U.S. AEC.

Mr. R. E. Bucknam as president of Gyra Electronics.

Mr. G. C. George as manager of project planning of Aerojet.

Mr. J. R. Carlin as manager of the newly formed Atomic Instrument Division of Atomic Associates.

Mr. O. A. Schulze as general manager of the engineering department American Machine and Foundry's atomics division.

Mr. R. Boutelle as chief health physicist of Martin-Nuclear.

Mr. J. Gronan as chief project engineer of Alco Products nuclear power engineering department.

Sir John Pascoe to the board of Timken Roller Bearings, Ohio.

Retirements:

Mr. C. Soukup, managing director of Richard Klinger owing to ill-health.

Tours:

Dr. J. N. Aldington, managing director of Siemens Edison Swan, to Canada.

Mr. P. Allan Charlesworth, a director of Electropol Processing, to the U.S.A.

Rear Admiral Helio Lopez, president of the Argentine National Commission on Atomic Energy, of U.K. AEA establishments.

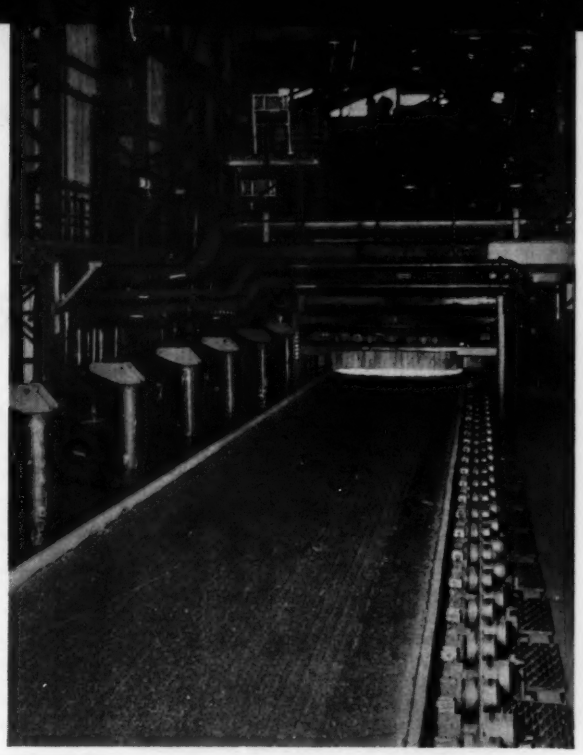
Dr. A. M. Brues of the Argonne National Laboratory, to major centres of radiation biology in the U.S.S.R.

Obituary:

Nuclear Engineering regrets to announce the death of the following:—

Mr. T. E. Goldup, of Mullards, on October 6, at the age of 65.

Industrial Notes



Sinter strand on the conveyor belt from the ignition hood and feed hopper at Stanton Ironworks' new £4m ore preparation plant near Nottingham. Designed to process between 25,000 and 30,000 tons a week the plant will enable the firm to improve the efficiency of the blast furnaces, increase the output of pig iron and allow reserves of low grade home ore to be used.

Plessey Nucleonics are to supply burst slug detection equipment for the Trawsfynydd power station. The equipment will be similar to that designed by the company for the majority of the nuclear power stations in the U.K. and the Latina station in Italy. Delivery has recently taken place of 50 single channel pulse height analysers to the AEA by Plessey's.

Dowty Nucleonics announce that, after careful consideration of the nuclear power station potentiality, they have decided not to engage further in production of nuclear equipment. They will, however, fulfil all existing contracts. The technical facilities and staff at Brockhampton Park will be employed on the development of new and more promising projects. Design and manufacture of sealed gas lubricated circulators and compressors will be maintained and carried on by Dowty Fuel Systems and the design and manufacture of high quality seals for the nuclear industry will be undertaken by Dowty Seals.

Mullard Equipment are building a 4-million electron-volt linear accelerator for X-ray treatment of deep-seated tumours for the Cancer Institute Board of Victoria, Australia. This is the fourth medical linear accelerator to be built by Mullards, the other three having been supplied to the U.S.A.

Two special furnaces, for annealing reactor fuel elements, have been ordered from **Birlec** by the AEA. The furnaces are of the cylindrical type, each rated at 40 kW and equipped with charge carriers accommodating 250 element tubes. They are capable of maintaining a high degree of vacuum (10^{-4} mm Hg) in the heating chamber to protect the charge, comprising uranium dioxide pellets in sealed beryllium tubes, against oxidation.

Electronic Instruments have developed a special survey trolley for monitoring radiation from the 50 MeV proton linear accelerator and the 600 MeV synchro-cyclotron at CERN. Designed by CERN the trolley contains two Vibron dose rate meters, one with a tissue equivalent ionization chamber and one with an argon chamber. Portable meters for slow neutrons, fast neutrons and gamma rays are also carried and the trolley is equipped with a battery and motor generator which enables it to be used in areas remote from mains power supplies.

CEGB is broadening the scope of its research activities to cover new operational problems arising from nuclear generation, states the Board's annual report published on September 29. More laboratories are being built at Leatherhead; new laboratories are being established near Berkeley and each of the five regions of the Board is setting up a research section. Current research is investigating stresses induced in bulk concrete reactor shielding by the temperature levels and gradients. This work is aimed at a possible increase in internal temperature. Test-plants have also been developed to provide data on the behaviour of Magnox fuel elements at high temperatures.

High Voltage Engineering have developed two new high energy microwave linear accelerators capable of generating intense x-ray outputs for radiographic inspection of materials. One is an 8 MeV, model LR-8, designed for inspection of thick sections of steel and complex mechanical and electronic assemblies of the nuclear and missile industries and the other model LR-15, a 15 MeV type, is designed for examination of solid rocket propellents.

Tube Investments announce that their research laboratories at Hinxton Hall, near Cambridge, are now in full operation. Research on beryllium will be undertaken at the laboratories.

Film Cooling Towers have moved to Chancery House, Parkshot, Richmond. Tel: Richmond 6494.

Powell Duffryn Engineering have been appointed licensees for the U.K. and Europe for the entire range of **Dempster-Dumpster** container handling vehicles and equipment. The equipment is the registered trade mark of Dempster Brothers, of Knoxville, U.S.A., and is specialized equipment for the handling of waste and process materials.

Evershed-Powertronic is the name of a new company formed in Canada by Evershed and Vignoles in the reorganization and enlargement of their Canadian activities.

The reorganization of **Isotope Developments** which is being made to increase efficiency will not after all involve Elliotts. A.E.I. is retaining its interest in the company.

Clarke, Chapman and Co., Ltd. (Victoria Works, Gateshead, 8), remind us that they, too, are amongst the main contractors at Latina. The company are fabricating 4,000 tube elements for the boilers and are also responsible for supervision of erection, testing and commissioning of the steam generating equipment.

20th Century Electronics, Ltd., of New Addington, Surrey, write to say that they are the sole manufacturers of the BMS 10/14 photomultiplier mentioned on page 354, October issue, *Nuclear Engineering*.

Lord Adrian opened a new laboratory for **Cambridge Instruments** on October 14 at the Cambridge works.

Catalogues

The **U.S.AEC** have published *TID-8507, Report of the Fuid Fuel Reactors Task Force*, which is available from the Office of Technical Services, U.S. Department of Agriculture, Washington 25, D.C.

The quarterly journal of the French electronic industry, *Telonde*, contains a comprehensive article on uranium oxide fuel production in France in its second edition, 1959. (79 Boulevard Haussmann, Paris 8c.)

Elliott Nucleonics have produced an attractive brochure outlining the company's activities. (Century Works, Lewisham.)

A catalogue, *G.100*, of the **Graviner** range of thermostats and overheat switches, is now available. (29 St. James's St., London, S.W.1.)

An attractive brochure outlining the activities of the **Ward Group** has been produced. (Albion Works, Sheffield.)

Honeywell micro switches are listed in a new catalogue. (Ruislip Road East, Greenford, Middlesex.)

A catalogue illustrating a new range of high vacuum equipment manufactured by **Genevac** has been produced. (Pioneer Mills, Radcliffe.)

Ransome and Marles have produced two new catalogues on the design for bearings and on ball and roller bearings. (Newark-on-Trent.)

Teddington Aircraft Controls have published a brochure on bellows expansion joints. (Carmarthenshire, South Wales.)

The manufacturing process for spirally welded tubes is described in a brochure available from **Viesteels,** 16 Northumberland Avenue, London, W.C.2.

Laing Year, describing the activities of the **John Laing** companies throughout the world, contains a section on the construction work at the **Berkeley** power station. (London, N.W.7.)

Research Reports

AEA Report, No. AEEW-M4

An interim report on the ZENITH Exponential Experiments . . . . by R. M. Absalom, I. R. Cameron, G. H. Kinchin, J. E. Sanders, D. J. Wilson

THE work is undertaken to obtain some initial understanding of the reactor physics of uranium 235-thorium-graphite systems of the type to be studied later in ZENITH, and this interim report has been issued to originate suggestions which may be usefully incorporated in the work before the facility is dismantled.

Two major considerations governed the decision on the compositions of the systems to be investigated: (a) one system should have a composition close to that originally proposed for the first critical loading of ZENITH, i.e. carbon atoms: uranium atoms=2860 and carbon atoms: thorium atoms=400; (b) all systems investigated should have the same ratio of carbon:thorium atoms (=400) to facilitate useful correlation of the data obtained with the various systems.

The materials under study have the following (nominal) carbon:uranium ratios: 5106, 3830, 2872 and 2393. Of these, 5106 has a thorium:uranium ratio of 12.66, 3830 has a ratio of 9.51, 2872 a ratio of 7.15, and 2393 a ratio of 5.97.

The experimental fuel element (of the ZENITH type) consists of a graphite cylinder, 2.9 in. o.d., 1.13 in. i.d. and 6 ft long, into which the uranium oxide, thorium oxide and graphite pellets are inserted to give the desired atomic ratios. All pellets have the same diameter, 1.11 in., but vary in thickness, the urania pellet being 0.068 in. thick and the thoria pellet 0.103 in. thick. Five thicknesses of graphite pellets are used varying from 0.8 in. to 0.068 in.

The loading pattern of the individual fuel element is based on equidistant thorium spacing which offers the additional advantage of assisting assembly and checking operations. Stratification effects in the assembled stack are avoided by inserting a 0.8 in. thick graphite pellet at the bottom of each alternate element.

The complete exponential assembly comprises 235 experimental fuel elements, in an upright position, resting on a graphite pedestal, 4 ft 6 in. square and 2 ft 4½ in. thick which, in turn, is seated on a ⅜ in. thick mild steel bed-plate. This is surrounded by a 1-ft thick concrete shielding up to a height of 2 ft. 6 in. Top and bottom reflectors are omitted. The upper ends of the elements are held in an aluminium grid plate, supported separately. The stack of fuel elements is arranged in an hexagonal array of 3-in. pitch. The system is excited by four half-curie Ra/Be sources, normally housed outside the concrete shield in flasks on the four sides of the graphite pedestal, and moved into position along two horizontal channels, at 90° to each other and intersecting at the vertical axis of the stack. The strength of each source is about 6 x 10^5 n/sec.

RESULTS

Extrapolated Radii

System	Height (cm)	Extrapolated Radius (cm)		
		N–S	E–W	NE–SW
S=5106/1	70	62.8	63.7	63.2
	100	63.15	63.5	
	120		63.8	
	150		64.1	
S=3830/1	70	63.7	63.7	63.2
	100	63.0	63.3	63.2
	120	63.4	64.0	63.5
	150	64.0	64.1	64.05
S=3830/2*	100	63.3	63.2	63.25

* Th-pellets paired.

Relaxation Lengths and Cadmium Ratios (Indium Foils)

System	Relaxation Length (cm)	Cadmium Ratio (average)
S=5106/1	38.6±1.1	2.45±0.05
S=3830/1	43.2±0.4	2.27±0.04
S=3830/2	43.8±1.0	2.27±0.03

Cadmium Ratio in Gleep core spectrum 5.27±0.20.

The major aim of the exponential experiment is to establish the vertical relaxation distance (l) of the flux and the extrapolated radius ($R+\Delta$) of the systems investigated. The present report deals, in the main, with the experimental work and a preliminary evaluation of the data thus obtained. The theoretical part of the work, concerned in particular with a determination of K_∞ from this data, includes a two-group analysis carried on in the ZENITH Group. A more rigorous comparison of theory and experiment will be provided by multi-group analyses of the exponential assemblies which are being made by the H.T.G.C. Technical Assessments Group.

The actual measurement of the fluxes is effected, in general, with BF_3 counters (Type 5EB40/13). As a check on the behaviour of the counters, the relaxation lengths are also determined, using indium foils. The spatial variation of the spectrum is followed by noting the variation of the cadmium ratio of the counter. In order to compare the neutron-flux spectrum, a cadmium ratio measurement was made in the known spectrum of GLEEP and compared with that measured in the exponential assembly, using the same (indium) foils.

Radial scans are made in four selected horizontal planes at 70, 100, 120 and 150 cm above the graphite pedestal respectively. The flux is studied in three directions, "N-S" and "E-W" parallel to the lines joining opposite pairs of the sources, and the third ("N-E"-"S-W") along a direction of 45° to the first two. Vertical scans are made in the inter-element channel adjacent to the fuel element in the centre of the stack and, in addition, in three channels at radii of 28.85, 28.85 and 26.76 cm respectively.

The possibility of direct streaming from the high-flux region at the bottom of the stack distorting relaxation distance measurements has been investigated and found to be insignificant.

Meetings

November 2.—The Institute of Marine Engineers, Merseyside and North Western Section (Liverpool Engineering Society, The Temple, 24 Dale Street, Liverpool 2, 6 p.m.). "Nuclear Propulsion of Ships," R. P. Kinsey.

November 3.—The Institution of Electrical Engineers, North-Western Centre (Engineers' Club, 17 Albert Square, Manchester, 6.15 p.m.). "The Application of Irradiation in Industry," M. C. Crowley-Milling.

November 4.—The Institution of Mechanical Engineers (1 Birdcage Walk, S.W.1, 6 p.m.). "The Design and Testing of Large Gas Ducts," A. T. Bowden and J. C. Drumm.

November 5.—The Institution of Electrical Engineers (Savoy Place, W.C.2, 5.30 p.m.). "The Application of Irradiation in Industry," M. C. Crowley-Milling.

November 5.—Liverpool Metallurgical Society (Library of the Department of Metallurgy, University of Liverpool, 7 p.m.). "Ductile Fracture," Professor R. W. K. Honeycombe.

November 10.—The Institute of Marine Engineers, Junior meeting (East Ham Technical College, Barking Road, East Ham, E.6, 7.15 p.m.). "Atomic Energy," K. Maddocks.

November 10.—The British Institution of Radio Engineers, Merseyside Section (University Club, Liverpool, 7 p.m.). "The Use of Transistors in Communications and Control," E. Wolfendale.

November 12.—The Institution of Electrical Engineers West Wales (Swansea) Sub-Centre (Conference Room, S.W.E.B. Showrooms, The Kingsway, Swansea, 6 p.m.). "A Review of Work Towards Nuclear Energy from Controlled Thermonuclear Reaction," D. W. Fry.

November 16.—The Institution of Electrical Engineers Sheffield Sub-Centre (Angel Hotel, Brigg, 6.45 p.m.) and South Midland Centre (James Watt Memorial Institute, Birmingham, 6 p.m.) on November 2. "The Electrification of the U.K.A.E.A. Industrial Group Factories," J. W. Binns and W. J. Outram.

November 18.—The Institution of Mechanical Engineers (1 Birdcage Walk, S.W.1, 6 p.m.) informal discussion "To what extent should design wait on research for nuclear power plant?"

November 18.—Bradwell Engineering Society (Staff Branch, 6.15 p.m.). "Nuclear Power—the 20th Century South Sea Bubble," K. L. Stretch.

November 24.—The Institution of Chemical Engineers (The Royal Institution, Albemarle Street, W.1, 2.30 p.m.). Symposium on Nuclear Energy. "The 2nd uranium production plant at Springfields," R. C. Alexander, L. P. Shortis and C. J. Turner. "The processing of uranium ores and concentrates to purified uranyl nitrate solution," H. Page, L. P. Shortis and J. A. Dukes. "The fluidized solids dryway process for the production of uranium tetrafluoride," E. Hawthorn, L. P. Shortis and J. E. Lloyd. "Pumping studies on aqueous thoria studies," R. Murdoch and H. A. Kearsey. "The use of hydrogen as a reactor coolant," D. Bradley.

November 25.—Manchester Metallurgical Society (Manchester Room of the Central Library, Manchester, 6.30 p.m.). "Engineering Aspects of Civil Nuclear Power Stations," B. D. Willson.

November 25.—The Institution of Mechanical Engineers, Thomas Hawksley Lecture (1 Birdcage Walk, S.W.1, 6 p.m.). "The effect of nuclear radiation on engineering materials," Professor A. H. Cottrell.

TRANSLATIONS

Résumés of Principal Articles

Elément Combustible à Flux transversal GEC (page 383).

Pour les réacteurs modérés au graphite et refroidis au gaz d'une puissance nominale élevée, la GEC a mis au point un élément combustible à flux transversal dans lequel le combustible, qui est de l'oxyde d'uranium, est contenu dans des boîtes lenticulaires en acier inoxydable montées transversalement par rapport à l'axe de canalisation à l'intérieur d'un manchon de graphite. Dans le dessin particulier qui a été l'objet d'une étude intensive, six rangées de tubes sont montées dans le manchon de graphite et maintenues en position par des supports en acier inoxydable.

On revendique pour cette méthode de disposition du combustible qu'elle assure un meilleur transfert total de chaleur pour de moindres pertes dues à la friction, et qu'elle simplifie un nombre de problèmes inhérents à la disposition en faisceau vertical des tiges de combustible préférée jusqu'ici dans la plupart des dessins de réacteurs. Une comparaison y est faite de capsules circulaires à coupe elliptique dont le taux d'axe majeur à mineur est de 3:1, un taux qui semble de beaucoup le meilleur à l'heure actuelle. Les chiffres indiquées, toutefois, ne sont pas considérés comme étant les meilleurs qui puissent être obtenus, et on effectue d'autres études de variantes de disposition d'empilage, de formes de tubes et de l'influence de diverses formes de rugosité.

Le Zénith (page 386).

Le premier réacteur à être mis en service au nouvel établissement de l'Atomic Energy Authority à Winfrith Heath, Dorset, sera le Zénith "Zero Energy High Temperature Experiment" (mot composé d'initiales: Expérience d'Energie Zéro à Température Elevée). Le réacteur est destiné aux études qui se rapportent au programme à Température Elevée et Refroidissement au Gaz y le noyau du ZENITH est chauffé au gaz et le réacteur aura pour but essentiel de fournir des données sur le comportement des éléments et réflecteur de combustible à diverses températures. Les éléments combustibles du ZENITH qui fonctionneront à 800° C. sont par eux-mêmes hors de l'ordinaire car ils comprennent des disques de combustible U-235 alternés avec du thorium, matière fertile, dans un tube en graphite. L'article qui décrit la conception du réacteur examine des variantes de systèmes de chauffage du noyau et présente des arguments convaincants en faveur de la méthode adoptée. Des dispositifs de contrôle sont décrits du même point de vue.

Recherches sur le Transfert de la Chaleur côté gaz (page 394).

Dans le cas d'une chaudière nucléaire une plus grande précision s'impose pour le calcul de la surface d'échange de chaleur que dans le cas des installations traditionnelles en industrie pour le transfert de la chaleur. Afin de faciliter cette précision, il faut pouvoir disposer de plus de renseignements, par example sur les facteurs de friction de l'écoulement par des assemblages de tubes à surface prolongée, ainsi que sur l'influence de divers paramètres tels que la grandeur et le pas des tubes sur les dimensions des chaudières.

G.E.C.—quer durchflossenes Brennstoff-Element (page 383).

Die General Electric Co. hat ein quer durchflossenes Brennstoff-Element entwickelt, in dem der Brennstoff, Uranoxyd, in linsenförmigen Hülsen aus rostfreiem Stahl enthalten und quer zur Achse des Kanals innerhalb eines Graphitmantels montiert ist. In der speziellen Konstruktion, die nach intensivem Studium gewählt wurde, sind sechs Reihen Rohre innerhalb des Graphitmantels montiert und in Position gehalten durch Stützen aus rostfreiem Stahl.

Es wird gesagt, dass dieses System der Brennstoff-Verteilung eine bessere totale Wärme-Uebertragung bei geringerem Reibungsverlust ergibt, und die Zahl der Probleme verringert, die die Anordnung von Bündeln von vertikalen Brennstoff-Stangen mit sich bringt, die bisher in den meisten Reaktor Konstruktionen den Vorzug gehabt hat. Es wird ein Vergleich angestellt zwischen kreisförmigen Hülsen und solchen mit elliptischem Querschnitt und einem Verhältnis zwischen grosser und kleiner Achse von 3 : 1, das z.Zt. als das Optimum erscheint. Die angeführten Werte sind indessen, wie man glaubt, noch nicht die besten, die man erreichen kann, und es sind weitere Prüfungen im Gange über eine andersartige Anordnung der Elemente, andersartige Rohrformen und über den Einfluss verschiedener Arten der Aufrauhung.

ZENITH (page 386).

Der erste Reaktor, der von der neuen Abteilung der Atomic Energy Authority in Winfrith Heath, Dorset, in Auftrag gegeben wird, ist ZENITH (Zero Energy High Temperature Experiment), der experimentelle Hochtemperatur Null-Leistungs-Reaktor. Er ist bestimmt für Studien in Verbindung mit dem Programm der Entwicklung der Gaskühlung bei hohen Temperaturen. Der ZENITH Kern wird mit Gas geheizt, und der Reaktor wird im wesentlichen gebaut, um Daten zu bekommen über das Verhalten der Brennstoff-Elemente und des Reflektors bei verschiedenen Temperaturen. Die Brennstoff-Elemente von ZENITH sind selber ungewöhnlich, indem sie abwechselnd Scheiben aus Brennstoff, U-235, und Anreicherungsmaterial, Thorium, in einem Graphitrohr aufweisen. Der Artikel, in dem die Konstruktion des Reaktors beschrieben wird, diskutiert dabei auch andere Systeme der Erhitzung des Kerns und bringt eine überzeugende Begründung für die gewählte Methode. Kontrolleinrichtungen werden von einem ähnlichen Gesichtspunkt aus beschrieben.

Untersuchungen über die Uebertragung der Wärme enthalten in Gasen (page 394).

Bei der Berechnung der in Wärme-Austauschern von Kernkraft-Anlagen zur Wärmeübertragung erforderlichen Fläche ist grössere Genauigkeit notwendig als im Falle üblicher Wärme-Austauscher für industrielle Anlagen allgemein. Um diese Berechnungen leichter zu machen, braucht man mehr Kenntnisse, z.B. über die Reibungskoeffizienten bei der Gasbewegung über Reihen von ausgedehnten Rohroberflächen, sowie über den Einfluss verschiedener anderer Grössen, wie Rohrgrösse und Neigung auf die Dimensionen der Kessel.

Elemento "GEC" de Combustible de Flujo Transversal (page 383).

Para reactores moderados al grafito y enfriados por gas de regimen elevado, la GEC ha evolucionado un elemento de combustible de flujo transversal en que el combustible, óxido de uranio, se halla contenido dentro de bidones de acero inoxidable lenticulares y montados transversalmente al eje dentro de un manguito de grafito. En el diseño especifico que ha recibido intenso estudio, hay seis hileras de tubos montadas dentro del manguito de grafito, siendo retenidas en posición por soportes de acero inoxidable.

Se reivindica que este sistema de disposición de combustible da mejor transferencia total de calor con menor pérdida friccional, y simplifica diversos problemas inherentes en la disposición de la agrupación vertical de varillas de combustible preferida hasta la fecha en la mayoría de diseños de reactor. Se hace una comparación de cápsulas circulares con una sección transversal elíptica teniendo una relación de eje de mayor a menor de 3 : 1, que en la actualidad parece óptima. No se cree, sin embargo, que las cifras citadas sean las mejores que pueden ser obtenidas y se están llevando a cabo estudios adicionales de disposiciones alternativas de hacinado, formas de tubos y la influende varias formas de rugosidad.

ZENITH (page 386).

El primer reactor a ser puesto en servicio en el nuevo establecimiento de la Autoridad de Energía Atómica en Winfrith Heath, Dorset, será ZENITH, el "Zero Energy High Temperature Experiment" (Experimento de Temperatura Elevada de Energía Cero). Destinado para estudios relacionados con el programa de Enfriamiento por Gas a Alta Temperatura, el núcleo del ZENITH es calentado a gas y el reactor servirá esencialmente para proveer datos sobre el comportamiento de los elementos y reflector de combustible a distintas temperaturas. Los elementos de combustible de ZENITH, que funcionarán a 800° C., son en sí poco usuales, ya que comprenden discos alternos de combustible, U-255, y material fértil, torio, en un tubo de grafito. Este artículo describiendo el diseño del reactor discute sistemas alternativos de calentar el núcleo y presenta un argumento convincente en pró del método adoptado. De un punto de vista similar, se describen dispositivos de control.

Investigaciones sobre Transferencia de Calor por el lado de Gas (page 394).

En el caso de una caldera nuclear, se exige mayor exactitud en el cálculo de superficie de cambio de calor que en el caso de una planta industrial convencional de transferencia de calor. Para facilitar esto, se necesita más información, por ejemplo, con relación a los factores de fricción para flujo a través de bancos de tubos extendidos de superficie, así como también con relación a la influencia de diversos parámetros, tales como tamaño y paso de tubos sobre dimensiones de calderas.

L'Instabilité Thermique dûe à l'Oxydation d'une Canalisation en Graphite par Laquelle passe un Courant d'air (page 400).

L'oxydation du graphite par l'air est fortement exothermique, le coefficient de température positif étant élevé à toutes les températures pratiques. Dans des conditions dans laquelle la chaleur engendrée par l'oxydation dépasse celle qui se perd aux alentours, la température du graphite doit augmenter à un taux croissant jusqu'à ce qu'une nouvelle source de perte de chaleur y mette fin. Des températures très élevées peuvent s'ensuivre.

Le but des recherches dont il est donné un compte-rendu a été la détermination des conditions dans lesquelles l'instabilité thermique peut se produire dans des réacteurs modérés au graphite et refroidis à l'air. Les résultats en seront particulièrement utiles pour donner des critères de sécurité pendant la recuite de ce genre de pile.

Le Contrôle de l'Humidité lors de la Construction des Chaudières (page 404).

Outre la nécessité du maintien d'une propreté absolue lors du montage d'un échangeur de chaleur nucléaire, il est aussi conseillable de veiller au réglage de la température et de l'humidité dans des limites serrées. L'appareillage employé à cette fin doit être portatif et en mesure de fonctionner de façon continue sans surveillance; il doit aussi pouvoir maintenir l'humidité et la température requises pendant la saison entière lorsque la température extérieure peut varier entre 4° et 27° C.

Une Méthode de Filtrage dans les Circuits de Gaz des Réacteurs (page 406).

Un problème d'une importance capitale dans le développement des réacteurs nucléaires refroidis au gaz carbonique est posé par le filtrage et les dispositifs collecteurs de poussières provenant de sources diverses, telles que l'érosion du noyau de graphite, et entraînées par le gaz. Par le passé, les caractéristiques d'arrêt des filtres appropriés ont été déterminées par la Spécification Américaine MIL–F–5504A qui stipule, dans le cas d'un filtre de 5 microns, par exemple, la retenue de 98% de toutes les particules entraînées dont la grosseur dépasse 5 microns, mais qui ne spécifie pas la grosseur des 2% des particules restantes dont le passage est permis. Une spécification plus sévère a été mise au point, et un nouveau filtre a été conçu qui satisfait aux nouvelles stipulations.

Les Grandes Sources de Radiation dans l'Industrie (page 408).

Environ deux cent hommes de science de 26 pays différents ont assisté à une conférence sur l'emploi des grandes sources de radiation dans l'industrie à Varsovie en Septembre. Les travaux, divisés en 3 groupes principaux, se rapportèrent à de grands groupes d'irradiation, au choix de la source, y compris l'emploi possible de fragments de fission; aux applications particulières de la radiation dans l'industrie chimique ainsi qu'aux applications particulières de la radiation dans les industries du pétrole, des matières plastiques et du traitement des denrées alimentaires.

Installation d'Irradiation de Produits en Paquets (page 410).

Une nouvelle facilité ayant une source de 150.000 curies a été installée au Labotaroire d'Irradiation de Wantage pour l'irradiation continue de produits en paquets. L'installation comprend un système complexe de classement automatique d'après lequel les paquets sont transportés d'un compartiment d'emmagasinage et faits passer à la source selon un programme de " temps d'exposition" prédéterminé.

Die thermische Unstabilität durch Oxydation eines luftdurchflossenen Graphit-Kanals (page 400).

Die Oxydation von Graphit durch Luft ist stark exothermisch mit hohem positiven Temperatur-Koeffizienten bei allen praktisch vorkommenden Temperaturen. Unter Bedingungen, unter denen die Wärme, die durch Oxydation erzeugt wird, diejenige übersteigt, die an die Umgebung abgeleitet wird, muss die Graphit-Temperatur im steigendem Masse anwachsen, bis der Anstieg durch eine neue Quelle aufgehalten wird, die Wärme abführt.

Der Zweck der Untersuchung, über die berichtet wird, war festzustellen, unter welchen Bedingungen thermische Unstabilität in luftgekühlten, mit Graphit moderierten Reaktoren entstehen kann. Die Resultate werden von besonderem Wert sein, um Sicherheits Kriterien für das Ausglühen dieses Typs von Atom-Meilern aufzustellen.

Feuchtigkeits-Ueberwachung während des Baues der Kessel (page 404).

Abgesehen von absoluter Sauberkeit während der Montage von Kernkraft-Wärmeaustauschern ist es auch ratsam, sowohl die Temperatur, wie auch die Feuchtigkeit innerhalb enger Grenzen zu halten. Anlagen für diesen Zweck müssen tragbar sein und im Stande dauernd zu arbeiten, ohne überwacht zu werden. Die Anlagen müssen weiter geeignet sein, die verlangte Feuchtigkeit und Temperatur während der ganzen Saison aufrecht zu halten, wenn die Aussentemperatur zwischen 250°F und 80°F schwanken kann.

Eine Filtrier-Methode für Kreisläufe von Reaktoren-Gas (page 406).

Ein wichtiges Problem bei der Entwicklung von Kernkraft-Reaktoren, die mit Kohlensäure gekühlt werden, ist das Problem der Filtrierung und des Abfangens von Staub, der von verschiedenen Quellen stammt, wie z.B. von der Erosion des Graphit-Kerns, und vom Gas fortgetragen wird. Bisher sind die Abfang-Kennziffern der entsprechenden Filter nach der amerikanischen Specifikation MIL-F-5504A beurteilt worden, die z.B. im Falle von 5-Mikron Filtern verlangt, dass 98% aller im Gas vorhandenen Partikel, die grösser sind als 5 Mikrons abgefangen werden, jedoch nichts über die Grösse der restlichen 2% Partikelchen besagt, die durchgelassen werden. Strengere Vorschriften sind entwickelt und ein neuer Filter ist entworfen worden, der den neuen Bedingungen entspricht.

Starke Strahlungs-Quellen in der Industrie (page 408).

Ueber zweihundert Wissenschaftler aus 26 verschiedenen Ländern trafen sich in Warschau im September zu einer Konferenz über die Benutzung starker Strahlungs-Quellen in der Industrie. Die Vorträge und Diskussionen waren in 3 Hauptgruppen unterteilt und behandelten grosse Strahlungseinheiten, die Wahl der Quellen mit Einschluss der Möglichkeit der Benutzung von Spaltungs-Fragmenten, die speziellen Anwendungen der Bestrahlung in der chemischen Industrie zusammen mit speziellen Anwendungen von Bestrahlung in der Oel- und der Plastik-Industrie und in der Nahrungsmittel-Konservierung.

Eine Anlage zur Bestrahlung von Packungen (page 410).

Eine neue Anlage mit einer Quelle von 150.000 Curies ist im Strahlungs-Laboratorium Wantage installiert worden zur fortlaufenden Bestrahlung von verpackten Produkten. Die Einrichtung besitzt ein umfassendes automatisches Fortschalt-System, durch welches die Packungen von der Lagerabteilung zur Quelle und dann an ihr vorbeigeleitet werden gemäss einer vorher eingestellten Bestrahlungs-Zeit.

Instabilidad Termica Motivada por Oxidacion de un Canal de Grafito Llevando un Flujo de Aire (page 400).

La oxidación de grafito por aire es fuertemente exotérmico con un coeficiente positivo de temperatura elevado en todas las temperaturas prácticas. En condiciones en que el calor generado por la oxidación excede la que se pierde en el ambiente circundante, la temperatura del grafito tiene que ascender a una razón progresiva hasta ser detenida por una fuente de pérdida de calor. Pueden resultar temperaturas muy elevadas.

El objeto de la investigación a que el informe se refiere, era para determinar en qué condiciones podría surgir instabilidad térmica en reactores enfriados por aire y moderados por grafito. Los resultados serán particularmente útiles para dar criterios para seguridad durante el recocido de este tipo de pila.

Control de Humedad durante la Construcción de Calderas (page 404).

Aparte de asegurar aseo absoluto durante el montaje de un cambiador de calor nuclear, es también aconsejable regular tanto la temperatura como la humedad dentro de estrechos límites. El equipo para este propósito ha de ser portátil y capaz de funcionar contínuamente sin atención; también ha de ser capaz de mantener la humedad y la temperatura exigidas durante la temporada entera cuando la temperatura exterior puede variar entre 25° F. (4° C.) y 80° F. (27° C).

Un Método de Filtración en Circuitos de Gas de Reactores (page 406).

Un problema mayor en el desenvolvimiento de reactores nucleares enfriados a dióxido carbónico es aquel de la filtración y colección de polvo originando de varias fuentes, tales como la erosión del núcleo de grafito, entrenado por el gas. En el pasado, las características de cortado de los filtros pertinentes han sido clasificadas en la Especificación Americana MIL-F-5504A que exige, en el caso, por ejemplo, de un filtro de 5 micrones, la retención del 98% de todos las particulas entrenadas mayores de 5 micrones, pero que no especifica el tamaño del 2% restante de particulas que se permiten pasar. Se ha evolucionado una especificación más estricta y se ha diseñado un nuevo filtro que satisface las nuevas estipulaciones.

Grandes Fuentes de Radiación en Industria (page 408).

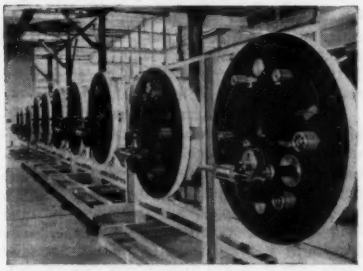
Unos doscientos hombres de ciencia de 26 países distintos, asistieron a una conferencia en Varsovia en el mes de setiembre sobre el uso de grandes fuentes de radiación en la industria. Los trabajos, divididos en 3 grupos principales trataron de grandes unidades de irradiación, la selección de fuente, incluyendo el posible uso de fragmentos de fisión; aplicaciones específicas de radiación en la industria química, juntamente con aplicaciones específicas de radiación en las industrias del petroleo, materias plásticas y del tratamiento de productos alimenticios.

Planta de Irradiación de Productos Empaquetados (page 410).

Una nueva facilidad con una fuente de 150.000 curies ha sido instalada en un Laboratorio de Irradiación de Wantage para la irradiación continua de productos empaquetados. La instalación comprende un complicado sistema automático de clasificación de acuerdo con el cual los paquetes se transportan de un compartimiento de almacenaje pasándolas a la fuente según un programa de " tiempo de exposición" prefijado.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.



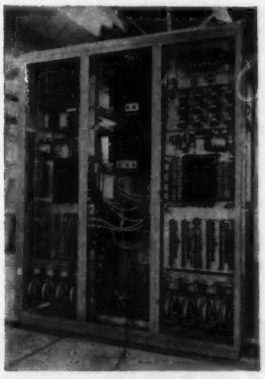
Burst slug detection precipitator units.

Instrumentation by Plessey Nucleonics

TO centralize the operations of the Plessey Group in the nuclear instrumentation field a new company, Plessey Nucleonics, was formed in 1956 with research and manufacturing facilities at Northampton. The size and scope of the new company has continued to grow and an extension to the factory nearly doubling the available area was opened by Sir John Cockcroft in July of this year. Present staff is something over 200 including 81 engaged directly on research and development projects. A team of mathematicians and theoretical physicists with access to computers is maintained to provide calculation facilities to the design teams and also customers. From the outset an unusually high proportion of effort has been put into research and the comprehensive range of internally designed equipment bears witness to this. Whilst a number of development contracts are handled particularly for military applications, the majority of the equipment has been developed with the company's own resources.

B.S.D. Equipment

Plesseys have always been in the forefront of burst slug (fuel element) detection equipment development and have now delivered, or have on order, complete installations or major components for the burst fuel element gear at the following stations: Calder Hall, Chapelcross, Marcoule, Bradwell, Hinkley Point, Trawsfynydd, Latina, AGR, Reaktor AG at Wurealingen, in Switzerland, FR2 at Karlsruhe in Germany, DIDO, PLUTO, and DMTR and the Canadian WTR. All these are based on the detection of gaseous fission products by precipitation of the solid daughter products on to a moving wire which is then counted by a shielded counter. The original equipment designed for Calder Hall (*Nuclear Engineering*, October, 1956, p. 286) has been considerably streamlined and a number of improvements made. The most obvious of these is the reduction in size, the massive cylindrical chamber as used at Calder being replaced by a much smaller unit made up of two flanged domes which bolt together to form a seal but are hinged to provide ready access to the winding mechanism. This has been made possible by a reduction in the weight of shielding for the counter which, from Calder Hall experience, was found to be unnecessarily heavy in the original design. All the assemblies inside the vessel are mounted on a single plate fixed like a web at the intersection of the two halves. The centre of the mounting plate is cut away to clear the precipitation chamber and the counter shield block, and the wire storage and drive pulleys are placed near the edges of the mounting plate surrounding the central assembly. The entire storage system is thus located in one plane and is readily accessible.



Rear view of timing unit of the burst slug detection monitors.

In the Mk. 1 design the wire was moved by an electric motor mounted outside the pressure vessel transmitting the drive through a pressure seal. The system is now replaced by a pneumatic system, the internal actuator driving through a ratchet to ensure accuracy of indexing. The pneumatic cylinder is actuated by the difference in pressure between the inlet system and the output from the compressor which returns the BSD gas back to the main circuit. Changes have also been made in the precipitator electrode which now comprises a stainless-steel coiled endless wire, the coiled arrangement giving a greater area for precipitation and also flattening the electric field characteristics in its immediate vicinity.

A further development, the Mk. 3 precipitator has reached an advanced stage of design; general principles are the same and work on prototype testing should begin shortly.

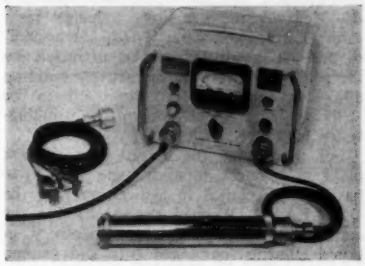
For BSD detection in water reactors a similar precipitation technique is used following scrubbing of a bleed from the coolant channel by helium gas. The system gives a high degree of sensitivity and a lower sensitivity in the detection equipment can be tolerated. A simple rod-type precipitator has been designed in which a cylinder actuated by a multi-stage solenoid is regularly presented to the incoming gas and then to the counter. A small compact unit results.

Development is also being undertaken on BSD selector valves, the prototype unit for Hinkley Point at present completing its final tests. This particular unit is designed to fit in a standpipe branch and to operate at a temperature of 350-400°C; a selector valve which can be inserted into the standpipe proper is also being designed.
1228

Radiac Equipment

Conscious of the need for a comprehensive range of Radiac equipment for Civil Defence and general monitoring purposes, Plesseys have on their own initiative developed a range of compact transistorized detectors.

The plutonium monitor type PNI 1080 is designed to detect contamination of wounds by plutonium. Previous practice has concentrated on the detection of the alpha particle but due to its small range this method is not satisfactory; the maximum body burden of plutonium is 0.04μc. In the decay of plutonium -239 a 17 keV γ-ray is associated with 4% of the disintegrations. Using a thin sodium iodide crystal in association with a selected low noise photomultiplier a portable battery operated unit has been developed which can detect half the total body burden if concentrated as a point source through 1 cm of flesh. The same apparatus can be used for detecting the 184 keV gamma-ray associated with the disintegration of U^{235}. The overall unit, excluding detector, is 9¼ in. by 6½ in. by 6 in. and weighs 13 lb. Included is a rate meter, register, single channel, pulse analyser, EHT supply and total power requirements are 15 W. Sensitivity is quoted as 15 counts/sec per μc Pu, with the background 0.2% of this figure.



Plutonium monitor, type PNI 1080.

The milk monitor type PNI 1085 is designed for the Milk Marketing Board for the measurement of fall-out activity in milk supplies. A simple shielded thin walled G-M tube is lowered into the milk churn, a microswitch on the support operates a counting unit and the contamination is shown on the instrument meter. This carries two scales, 0-3 tolerances and 0-150 tolerances arranged on either side of a central zero to avoid misinterpretation. Power may be derived from a 12 V car battery or a.c.

mains. The instrument calibration in terms of tolerances is based on an m.p.c. for milk of 1,000 d/min per ml, corresponding to 5×10^{-4} μc/ml. The response time for the instrument is set at 20 sec. Again transistorizing has led to a compact unit, the main instrument cabinet weighing only 8 lb.

For measuring contamination of food the Ministry of Agriculture, Fisheries and Food unit 1045A has been produced. This is a counting unit which can operate with G-M tubes and would normally be associated with a lead castle. The instrument is provided with a ratemeter giving meter indication of 10 to 500 counts/sec and a register covering the range of 0-25 counts/sec. Power supplies can be from a 9-V dry battery, an external vehicle accumulator, or from the mains. Time constant of the instrument is normally 5 sec, although 1 sec can be used with a hand probe. Lifetime of the instrument using the internal dry battery is approximately 400 hours. Total weight again is about 8 lb.

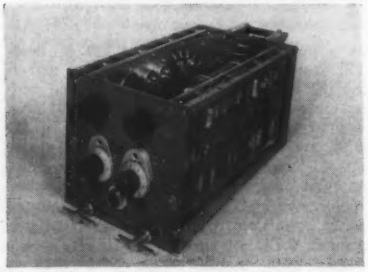
The PNI 1065 also transistorized is similar to the 1045 but with the additional capacity of using a scintillation counter as the probe. Stability of the EHT is quoted as 0.1% for 1% change in the supply voltage and is adjustable over the range 300-1,500 V. Time constant of this instrument is 3 sec and the meter is calibrated from 10-1,000 counts/sec.

The 1075A is a general purpose, portable, dry battery powered detector along similar lines.

These last named instruments all have semi-log scales as also has the 1072, a monitor designed specifically for detecting and if necessary recording background radiation.

To meet the specification of the Ministry of Housing and Local Government for monitor water supplies the company is developing a monitor which incorporates a β/γ detector in a cation exchange resin through which the water is fed. Some 90% of fall-out products will be extracted by the resin and a plot of the activity build-up allows a sensitivity of 10^{-11} c/l to be achieved. This is one-tenth of the drinking-water tolerance.

For monitoring the outfall from effluent plant an effluent monitor type PNI 1046 has been developed in association with the U.K.AEA. Designed specifically for the continuous monitoring of radioactivity in liquid effluents, combined beta and gamma



Single channel pulse height analyser.

activities are measured by a thin wall immersion-type G-M tube, but an alpha-sensitive scintillation counter can be substituted. The associated pipe-work and pumps are in stainless steel, the effluent being presented to the 200 cc sample vessel at a rate of flow which is adjustable from 2-15 cc/sec. The detector is automatically

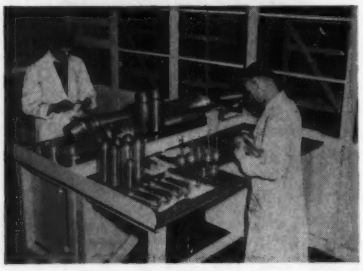
Cadmium sulphide detector with indium contacts mounted on a Perspex backing (actual size).

cleaned in water once a day. The ratemeter with a range from 0.3-3,000 counts/sec is associated with pre-set high and low count alarms. A count of twice normal background occurs when specific activity is 10^{-6} c/l of strontium−90 or 10^{-7} c/l of caesium−137. For normal fission product mixtures the comparable activity is $3\text{-}6\times10^{-6}$ c/l. The alpha sensitivity of the instrument is 10^{-7} c/l. The equipment is housed in a standard 5-ft rack and is mains operated, the power consumption being 600 W.

1229

Reactor Instrumentation

The company offers a complete range of equipment for reactor instrumentation; the present preferred designs are based on thermionic valves but transistorizing is in



Ion chambers being assembled.

process. A complete flux measuring system would comprise low level pulse counting channels based on BF_3 proportional or fission counters, intermediate and high level channels using logarithmic d.c. amplifiers, fed from ion chambers and capable of scanning six decades, shut-down channels fed from ion chambers which operate the maximum power trip, high power linear channels again using ion chambers and covering two to three decades, and drift channels.

The reactor shut-down amplifier type PNI 1018 compares through a 50 c/sec chopper amplifier system the voltage developed across the load resistance of a mean current ion chamber with a pre-set reference voltage calibrated in terms of reactor power. When these two are equal the trip relay is initiated to shut the reactor down and an alarm circuit operated; meter indication is given of pre-set power level and of power to shut-down. Shut-down setting utilizes a ten-turn potentiometer with three figure digital indication. Setting is within 1 MW on a 250 MW range.

The reactivity meter type PNI 1019 is used in the logarithmic power channels, for giving an indication of the rate of change of neutron flux. This instrument is based on the AERE reactivity meter type 1519A. The indication of the instrument shows a doubling time range of -20 to ∞ to $+5$ sec presented on a 4-in. meter. Accuracy is quoted as $\pm6\%$. The unit can be calibrated to give 5 sec doubling time indication when the voltage is changing at any rate between 0.4 and 0.75 V/sec going positive. The differentiating time of the instrument is 20 sec and the integrating time 1 sec. The 1019/1 is similar but differs in respect of range and input polarity.

The PNI 1037 linear d.c. amplifier is suitable also for general laboratory applications. Useful range of current measurement is 10^{-13} to 10^{-5} A; the input resistors being decade spaced from 10^6 to $10^{13}\Omega$. Two voltage ranges are provided 0-3 and 0-10 V either positive or negative. The long-term stability is better than $\pm3\%$ and for a $\pm10\%$ mains voltage variation a drift of less than 10 mV is seen. Output is shown on a 4-in. meter and pre-set high or low level trips can be included.

PNI 1036 log d.c. amplifier is suitable for the range 10^{-13} to 3×10^{-7} A, but an extension is possible down to 10^{-13} or up to 10^{-6} A by the selection of special input valves. Accuracy is specified as $\pm10\%$. The amplifier comprises input electrometer stage with a d.c. amplifier fed back to the electrometer screen, followed by the trip circuits. PNI 1066 is for the range 3×10^{-11} to 3×10^{-5} A with the same accuracy, otherwise the general specification is similar to the 1036.

The logarithmic ratemeter type PNI 1058 is based upon a multiple diode pump system and covers up to 5 decades. Meter indication is given of count rate, EHT voltage and high and low current alarms are provided. Count range is 0.3-30,000 counts/sec, the ratemeter section being preceded by an amplifier with a gain of 20 and a discriminator, the trigger level of which may be pre-set between 0.4 and 4 V. A stabilized power supply provides 2,000 V at 200 μA.

1230

Counter Development

Considerable effort is devoted to the development of ion chambers and counters suitable for incorporation in reactor control systems. These are assembled in special clean area rooms with 2-5μ filtration. The original standard design of ion chamber has been modified over the years and ceramic insulation is now used throughout. An interesting development to improve gamma compensation is the use of tapered electrodes which can be adjusted to change the relative volumes of detection and compensating sections. Ion chambers can be operated in temperatures up to about 200°C the precise upper limit depending upon the sensitivity required and the filling pressure. Two standard units are currently available the PNI 1025 two electrode chamber, and the PNI 1026 a three electrode chamber with γ compensation but not adjustable.

The PNI 1049 is a neutron detector of the fission counter type. Such a counter can be operated in gamma fields of up to 10^5 r/hour without difficulty. Rise time of the output pulse is less than 100 n sec; the counter has good saturation characteristics. A polarizing voltage of 1 kV is recommended. The coated area is 200 cm² and the normal sensitivity range is from 0.02 to 0.2 counts/neutron per cm².

Crystal Detectors

An important section of the development concerns the investigation of cadmium sulphide and cadmium selenide crystals as medium level radiation detectors. The basic trouble with these detectors in the past has been the long response time and the very big memory effect. The potential advantages of crystal detection have been known for many years, but those crystals which would give a satisfactory performance have, on the whole, been freaks. One of the companies of the Plessey Group is now producing crystals which have a high degree of uniformity in performance; these exhibit no memory and the response time is of the order of 1 sec.

It is still too early to say whether cadmium sulphide or cadmium selenide will be used, but these crystals in association with a plastic phosphor and polarized with 10 V are capable of giving an output of several μA/r. They open up the possibility of producing detectors in which virtually the whole volume and weight is in the indicating meter and polarizing cell.

The same crystals are also being used as photosensitive switches for thermocouples. With no contact potentials to confuse thermocouple readings the vast change in resistance exhibited by these crystals when irradiated with visible light considerably simplifies the data processing of a large number of thermocouple readings.

(*Plessey Nucleonics, Ltd., Weedon Road, Northampton.*)

1231

Transistorized Nucleonic Instruments

Elliott Nucleonics now make a complete range of transistorized reactor control instrumentation, together with transistorized counting equipments and d.c. trip amplifier units. The complete reactor control equipment comprises seven items each constructed from a series of sub-units of standard sizes which are plugged into a chassis assembly to form a complete unit suitable for P.O. rack mounting. Each sub-unit is designed as a separate functional unit allowing various main equipments to be built up from different combinations of sub-units.

The most significant achievement in the use of transistors is the reduction in the amount of heat generated by the equipment. In the case of the pulse channel the transistorized unit dissipates only 10 W as compared with roughly 500 W in the case of the equivalent thermionic units. This means that the heat dissipated is reduced by a factor of about 10. No external cooling is required as the temperature rise is extremely small.

Space-saving by the use of transistors is well known and in the case of a pulse-counting channel, 80% is saved in this new equipment. Servicing problems have been considerably eased by the plug-in arrangement of the sub-units. It is also practical to operate from a battery but normal operation is from 50-cycle mains.

1232

Comprehensive rate and period meter.

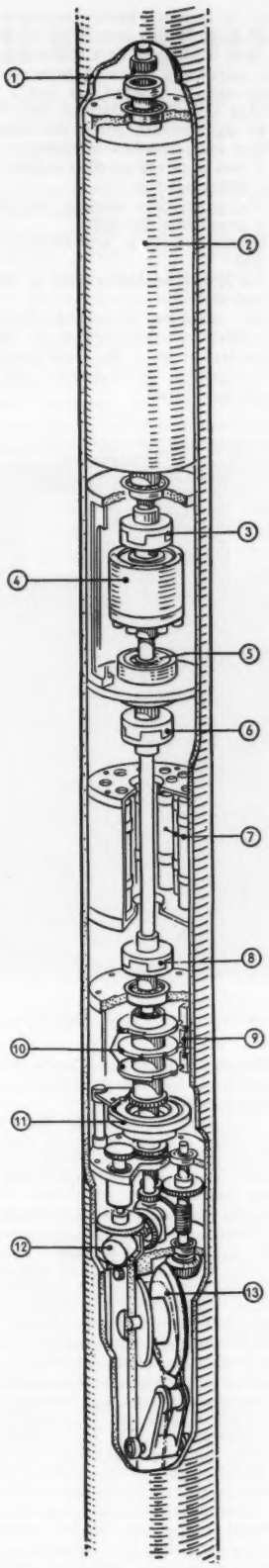
Simulator

A nuclear power plant simulator has been developed for the CEGB by Elliott Nucleonics. This board, designated for the Berkeley power station, will be used to train operators. The unit has been designed to simulate a graphite moderated, gas-cooled, natural uranium fuelled reactor with six heat exchangers and using a dual pressure steam cycle. It can also be adapted to represent other reactors having different fuels and moderators.

1233

AGR Control Rods

Also shown for the first time recently was the control rod mechanism for the advanced gas-cooled reactor being built by the AEA at Windscale. The mechanism has been designed by Elliott engineers in conjunction with the AEA. The control rod, which weighs 214 lb, is raised and lowered through a height of 20 ft and is suspended by a stainless steel wire tape which is wound on a drum in the lower part of the mechanism. The drum is driven through spur and bevel gearing by a permanent magnet synchronous motor which controls the position of the rod when supplied with a variable low frequency and zero frequency three-phase alternating current. An electrical transmission obtained from a synchro which is geared to the drum drive indicates the position of the rod on a central control desk.



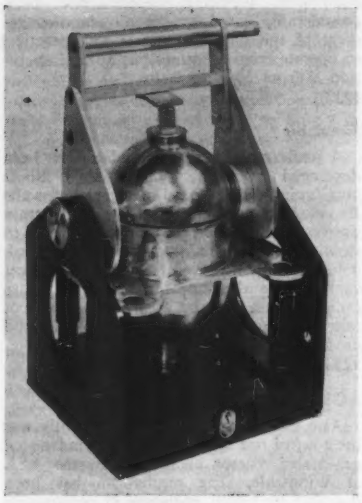
General arrangement of an AGR control rod drive developed by Elliott Nucleonics in conjunction with the AEA.

1. Emergency winding gears. 2. Permanent magnet synchronous motor. 3. Coupling. 4. Free wheel. 5. Ball bearing. 6. Coupling. 7. Braking resistors. 8. Coupling. 9. Braking switches. 10. Switch operating cams. 11. Positioning cam. 12. Control rod position synchro transmitter. 13. Winding drum assembly.

Fixed rate of withdrawal of the rod is 0.006 in./sec and there are two rates of insertion, 0.006 in./sec and 0.060 in./sec. Control of the fall of the rod under gravity during emergency conditions is by regenerative braking of the motor and requirements are that the rod should fall through the normal operating distance of 14 ft in a maximum time of 5 sec, travelling the first 7 ft in less than 1.5 sec and braking over the last 7 ft to reach a terminal velocity which does not exceed 1 ft/sec. Loss of tape tension is indicated by a micro switch actuated by a spring-loaded bell-crank carrying the tape guide pulley, and a second micro switch, actuated by a cam, operates a circuit giving a warning when the position is approached at which the rod enters a latch mounted below the mechanism. A freewheel in the motor drive prevents overwind of the tape beyond the fully inserted position of the rod.

The control rod has been designed to fit in a stand pipe of 5.62 in. bore and to operate in an atmosphere of carbon dioxide gas at a pressure of 270 p.s.i. and a temperature of 150°C at the winding position. Air cooling on the outside of the stand pipe controls the temperature in the region of the motor and maintains it below 100°C. Arrangements have been provided in the seal plug at the top of the mechanism for the connection of a portable winding device to enable the rod to be withdrawn in the event of a motor failure.

1234



New gamma container.

Isotope Containers

A new range of gamma containers designed to hold the activities commonly used in radiography has been produced by Gammax. Weighing 37 lb. the standard container is for caesium—137, iridium—192 and up to 200 mc cobalt[60]. A smaller size weighing 12 lb is intended for transporting thulium—137 and lower activities of iridium—192. Both containers have been designed to conform with safety regulations as published by the International Labour Office.

The containers consist of three parts, two hemispherical lead blocks and a pencil housed in the upper hemisphere, containing the source. By moving the operating handle the upper hemisphere is rotated through 90° to expose the inner source container. This can be removed by a handling rod provided for open source radiography. The standard container is arranged for remote control and there is also a built-in patent lock. Lead-lined transportation cases are provided for additional shielding.

(Gammax/Pontet Ltd., 47/51 Wharfdale Road, London, N.1.)

1235

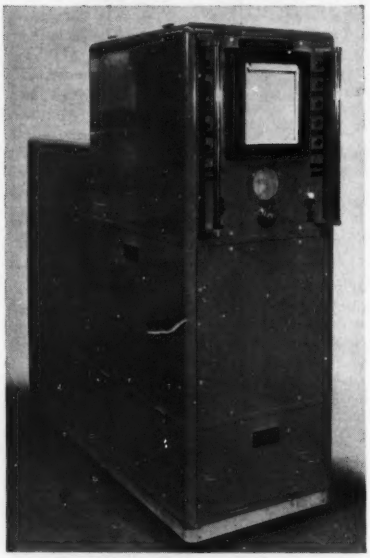
Beryllium Monitor

An automatically-operated mechanical sampling equipment for determining the concentration of beryllium dust in air has been designed by Glass Developments for the U.K. AEA. The equipment is suitable for handling six samples per hour, presenting them to a recording ultra-violet emission spectrometer capable of analysing a liquid solution. The sample is submitted to several processing phases before it is passed to the spark-chamber.

In operation, 100 litres of air are sampled every 10-12 minutes. The range is 0.25 to 25 tolerances (1 tolerance is 2 microgrammes per cubic metre) and readings are presented on a strip chart recorder. The principle of measurement is solution of the dust in sulphuric acid and analysis of this solution with an emission spectrograph. With this method, errors due to the chemical state and particle size of the dust are avoided. The monitor will function automatically and continuously for 10-hour periods without any attention. Audible and visible alarms are operated if the beryllium concentration exceeds a pre-set level. Interlocks are incorporated and also operate the alarms.

The dust is collected on a continuous strip of filter paper and a disc of paper carrying the dust stain is punched out into a small dish. The dish is transported by a turntable to six positions where the following operations are performed in sequence:—

(1) A dish is placed on the turntable from a dish magazine.
(2) The paper disc carrying the dust is dropped into the dish.
(3) Sulphuric acid is dispensed into the dish.
(4) The dish is heated to dissolve the dust and paper.
(5) The solution is cooled. Scandium sulphate solution used as an internal standard in the spectrographic measurement is dispensed and the mixture stirred.



Beryllium dust sampling equipment.

(6) The dish is placed in a spark-chamber and after sparking is dropped into a waste receptacle.

The two carbon electrodes are ejected after sparking and the new ones dispensed from magazines into the spark-chamber. All the operations are controlled by sequence controllers.

To avoid corrosion the acid fumes are extracted from all the operating positions of the dish and discharged through a chemical filter. The magazines hold 50 dishes and 50 of each type of electrode, sufficient for 10 hours' operation. The acid needs replenishing after about 100 hours. The monitor is mounted on a trolley and may be moved easily. Its width of only 20 in. enables it to be used in narrow passage-ways.

The monitor is used for aerosols other than beryllium and can be modified in several respects. It can, for example, be adapted for the semi-continuous analysis of other liquids and the chemical processing may be adapted to the problem in hand. Glass Developments are prepared to carry out design adaptations of the automatic sampling equipment, in co-operation with the users, for specific analytical purposes.

(Glass Developments Ltd., Sudbourne Road, Brixton Hill, London, S.W.2.)

1236

Dust Removal at Springfields

At the AEA's Springfields works the handling of toxic dust has required special consideration and six separate vacuumation systems have been installed by BVC. Essentially vacuum cleaning systems designed to remove surface deposits of dust and powder, these units are notable for their successful employment of a novel cyclone method, which is not only efficient but ensures disposal of hot dust with the maximum degree of safety.

Dusts created at Springfields possess various properties, and it was essential for a number of reasons that these should be collected and neutralized with the greatest possible speed. The installations needed unusually careful planning, and were designed to two different arrangements to meet the layout of other plant and services. One of these systems covers 26 collection points and the capacity of the plant allows up to 8 points to be open to suction at any one time.

Undoubtedly the most interesting fact about these installations is that, due to the nature of the powders and dusts collected, no accumulation of dust is permitted in any dry state. This condition, of course, precluded the use of conventional dust separators with fabric filters. To deal with the immediate collection of dust from the pick-up points by this method, high efficiency cyclones were introduced, which incorporated a unique wetting and dust-arresting feature. The dust, when picked up through the cleaning nozzles, is precipitated in the cyclones and held by the wet sump. This means that the whole of the inter-connecting pipework system, which is normally a dust conveying line, is employed purely for the passage of air, being completely free from dust particles. The dust is also collected in sealed boxes in which certain production processes are carried out. To handle this problem with the greatest degree of economy of suction power, automatic closing valve tools are actually retained in the boxes, and are handled by operators through glove ports.

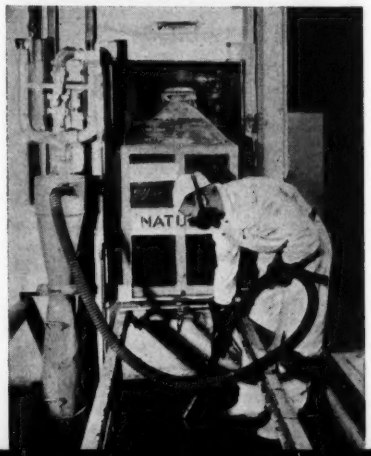
As a safeguard, secondary cyclones are incorporated in the systems, being located adjacent to the air exhauster units.

A second vacuumation system has a similar function, but in this case, due to the nature of the powders and dusts handled, the wet sump feature of the primary cyclones gives rise to the development of gas. To overcome this condition and to prevent pressure build-up during operation, explosion vents are incorporated above each primary cyclone. To ventilate each cyclone, the inlets and suction control valves and the outlets are arranged with pilot holes, these ensuring that when the primary cyclone is isolated from the suction lines, there is a small air throughput to disperse any gas accumulation.

(British Vacuum Cleaner and Engineering Co., Ltd., Leatherhead, Surrey.)

1237

Vacuum system for dust removal.



NEW BOOKS

Chemical Processing of Nuclear Fuels. By F. S. Martin and G. L. Miles. (242 pp. Butterworths Scientific Publications, Ltd., 1958.) 40s.

This book is concerned with the chemical processing of reactor-irradiated nuclear fuels. No specific discussion is presented of the initial preparation of materials for use as fuels in reactor systems although some of these preparative procedures are considered inasmuch as they are also employed with irradiated fuels.

The text is divided into five parts, of which the first surveys the factors which determine the need for chemical processing, notably the recovery of both unfissioned or recently-bred fissile fuel and fertile fuel. Part I is necessarily brief, since consideration must be given to such diverse topics as the characteristics of present and future power reactors and their fuel systems, the formation and nuclear properties of reactor poisons and the contribution of processing costs to the overall costs of nuclear power.

Present large-scale separation processes, which largely involve selective partitioning of elements between an aqueous and an organic phase are treated at length in Part II entitled, somewhat inappropriately, "Aqueous Processes." The solution chemistry of the actinides and the important fission-produced elements is surveyed in the opening chapter. Inevitably with such a survey, points of disagreement arise such as the implication, when discussing the equilibrium between the valence states of plutonium (p. 70), that any one electron-transfer reaction must proceed rapidly. Whilst the authors state that only "unfamiliar aspects" of the elements will be presented, it is somewhat of an anticlimax for the chemist to read that "rubidium and caesium are highly electropositive and form singly-charged ions in solution" and that "aluminium hydroxide is amphoteric and may react in three ways." However, these intellectual pin-pricks are the reviewer's privilege. The overall picture presented by this survey is adequate for the purpose.

Part III deals with separation methods which are not yet in full-scale use, but which in some cases hold promise for the more advanced reactors of the future.

Part IV is a relatively brief section on effluent disposal and fission product recovery. The treatment that the authors present serves to indicate the multitude of problems which still await an adequate solution. Part V is a single chapter which speculates on future requirements for fuel processing.

The authors are to be commended on their very readable treatment of quite a broad field and the text should be useful not only to those involved in the nuclear power industry but also to all seeking an authoritative account of the field.

D.R.S.

Chemistry of Nuclear Power. By J. K. Dawson and G. Long. (208 pp., George Newnes, Ltd., London, 1959.) 30s.

A general and very readable account of the chemist's contribution to the development and commercial utilization of nuclear power. The coverage of the book is wider than other books written on a similar theme and understandably its discussion of individual topics is rather more superficial. The specific function of this book is to present a coherent account of the many diverse topics involved in the chemistry of nuclear power and the authors are to be congratulated on the success of their efforts. The text is well suited to the needs of those just entering the field of nuclear power and to those desiring a general account of the topic.

A general introduction is followed by the principles of the preparation of the basic reactor materials: Uranium, thorium, graphite, deuterium and heavy water. The reader may be at a loss to assess which concentration process is the most appropriate for deuterium preparations; the inclusion of the separation factors for all the processes described and the basic mathematical relations for cascade separations would have assisted without prolonging unduly the discussion. A brief account of the fission process leads to a useful treatment of the significance of reactor poisons, although here again no mathematical relations for the rate of growth and decay of these poisons are presented.

The separation of plutonium, uranium and fission products from irradiated fuel elements and the separation of uranium from irradiated thorium are discussed but here, greater emphasis might have been placed on the separation efficiencies which must be attained for the successful chemical treatment of irradiated fuel elements. Specific points such as the dissolution of canning materials and the future use of radiation resistant inorganic ion exchangers might also have received more attention.

After a short chapter on the handling of radioactive materials, the book is largely devoted to chemical problems arising in nuclear reactors, especially water-cooled and gas-cooled reactors. It is gratifying to see that radiation-induced decomposition reactions, often the limiting factor in reactor design, are given more treatment than in rival texts although radiation chemists would disagree with the finer details of the mechanism proposed for the radiolysis of liquid water. The final chapters outline problems in the disposal of radioactive waste and possible chemical uses of radiation and thermal energy from reactors. The general impression created is one of very limited optimism especially where chemical synthesis is concerned.

D.R.S.

Thorium Production Technology. By F. L. Cuthbert. (303 pp., Addison-Wesley Publishing Co., 1958; 10-15 Chitty Street, London, W.1.) 49s.

This book justifies its title with an account of the occurrence, extraction, fabrication and properties of metallic thorium particularly suited to the extraction metallurgist or chemical engineer. The compounds and alloying behaviour of thorium are only briefly discussed. As the book has been under the supervision of only one author, it does not suffer the unevenness of style and occasional duplication noticeable in the A.S.M. publication "The Metal Thorium," the only comparable text. Its writing coincided with the fall of interest in thorium for nuclear purposes and the consequent reduction in the volume of research and development work; as a result few recent developments are omitted. Exceptions are the cellulose phosphate ion exchange process and the techniques for treating Blind River uranium barrens.

The conventional processes for extraction from the ore are treated in considerable detail, and the account of the solvent extraction pilot plant is excellent. Non-standard or laboratory processes are treated perhaps more briefly than they deserve. The chlorination route is, for example, a potentially simple process, already used for zirconium, which with the advent of improved materials of construction and cheaper chlorine would become more attractive. Standard processes for the extraction of the metal from its compounds are treated equally comprehensively. Preparation of the chloride electrolysis cell feed could have been treated in greater detail, particularly as a simplified semi-continuous technique has been developed in the United Kingdom. The account of the properties of thorium, although not as comprehensive as that in "The Metal Thorium" is complete and concise.

There is an occasional careless use of terms; for example, increasing the particle size of thorium powder does not change it from the amorphous to the crystalline form; and filtering is a recognized chemical process, but not filtrating. However, these are minor faults in an otherwise valuable work.

R.G.B.

Books Received

Principles of Radiation Dosimetry. By G. N. White. 124 pp. John Wiley and Sons, Inc., New York; Chapman and Hall, Ltd., 37 Essex Street, London, W.C.2. (1959.) 56s.

International Directory of Radio-Isotopes. Vol. I. (Unprocessed and Processed Radio-Isotope Preparations and Special Radiation Sources). 263 pp. The International Atomic Energy Agency, Kaerntner Ring, Vienna, 1. (1959.)

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Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 807,493. Process for the purification of alkaline-earth metals by distillation at reduced pressure. Deutsche Gold- und Silber-Scheideanstalt vorm. Roessler. (Germany.)

A process of purifying calcium by vaporization and condensation at reduced pressure. The solid crude metal is covered with a thin liquid layer of an alloy formed from the metal to be distilled and one or more metals with a lower vapour pressure than calcium. Suitable alloying metals are nickel, lead, cobalt, copper, tin and, in particular, aluminium. The alloy is used in the form of a foil wrapped round the metal to be purified. During the distillation process harmful impurities will be retained by the alloy layer and the metal condensate will thus have a degree of (nuclear) purity high enough for it to be used as a reducing metal in the production of uranium and thorium. The method may also be used for the recovery of other alkaline-earth metals such as strontium, barium and magnesium.

B.P. 807,751. Fuel elements for nuclear reactors. K. H. Dent and U.K. Atomic Energy Authority.

Details are given of a vertical fuel element assembly with a spider support. The spider has a boss for attachment to a fuel element and retractable spring-loaded legs, hinged to the boss and held in a downward position by a catch. On striking the catch the legs move to an extended position.

B.P. 807,817. Fuel-breeder fuel element for nuclear reactor. U.S. Atomic Energy Commission. (U.S.A.)

A central core of fertile material (thorium) in a container is surrounded by a first bonding material (fused fluoride salts, sodium, sodium-potassium, bismuth, bismuth-tin), a sheet of fissile material (uranium) immediately surrounding the first bonding material, and a second bonding material (which could be the same as the first bonding material) in contact with the container.

B.P. 808,095. X-ray radiation detector. Philips Electrical Industries Ltd. (U.S.A.)

The detector described is suitable for measuring X-ray radiation of a wavelength longer than about 1.5 Å (soft radiation) and has a window less than 25 μ thick, made of beryllium.

B.P. 808,381. Nuclear reactor fuel element handling plant. R. A. Taylor and Babcock and Wilcox Ltd.

A chute for conveying spent fuel elements from a higher to a lower level, with the special feature of braking the speed of the elements in transit effectively enough to cause some of them to come to a complete standstill in a given area of the chute. Further movement of the element to the discharge point is then effected at a slower pace by directing water jets on to the elements.

B.P. 808,477. Decontamination of neutron-irradiated uranium. Atomic Energy of Canada Ltd. (U.S.A.)

The uranium is heated with an anhydrous chloride of lithium, sodium, potassium, rubidium, caesium or magnesium (sodium or magnesium preferred) in an inert atmosphere at a temperature above the melting point of uranium (1,130°C). Chlorides of plutonium and fission products are formed and the decontaminated uranium can then be removed.

B.P. 808,726. Radiated energy-absorbing materials. Eltro G.m.b.H., Ges. fuer Strahlungstechnik. (Germany.)

Refers to building materials, especially those consisting of known aggregates, mixed with binding materials (magnesium oxide, magnesium chloride, cement). The best conditions for the absorption of high-energy radiation can be obtained by admixing at least one of the materials known to promote the conversion of high-energy radiation into radiation of lower energy. The latter can be absorbed at least in part by the building material itself or by the admixed material. Suitable for admixture are the following: paraffinic hydrocarbons, cadmium, cadmium oxide (sulphate, tungstate or other inorganic cadmium compounds, excluding binary compounds of cadmium and an element of Group VIb of the Periodic Table), inorganic selenium compounds (excluding binary compounds of selenium and an element of Group II of the Periodic Table), heavy metals and inorganic compounds of the heavy metals other than sulphides, selenides, tellurides of bismuth, lead, arsenic, antimony or thallium.

B.P. 808,775. Electroscopes for radiation detection. R. P. Henderson and Philips Electrical Industries Ltd.

A portable electrostatic dosimeter with a (quartz) fibre as indicator viewed through a microscope. The compound eyepiece has a plano-convex field lens with an outwardly facing plane face on which the graticule is provided by the deposition of an opaque metal coating through a stencil by evaporation of the metal in a vacuum. The microscope objective is arranged to form a real image of the fibre in the plane of the graticule. In contrast to photographic film graticules, an opaque metal (aluminium) coating produced by the vacuum evaporation technique directly on the plane face of the lens does not present mounting and aligning problems and the lines are sharply defined.

B.P. 808,795. Irradiating devices. Philips Electrical Industries Ltd.

Irradiating devices employing radioactive materials such as Co-60 and Cs-137 as the radiation source present difficulties in design, particularly with regard to suitable provisions for controlling the radiation intensity and stopping radiation altogether when desired. One known solution uses mercury to block the passage of the radiation by filling the channel, from which the rays emerge, with the metal. In operation, compressed air keeps the channel free from mercury. The present invention describes an improved design, using mercury as before but not compressed air. Here, the mercury is contained in a channel with the radiation source (capsule) in a fixed position, the channel being defined at one end by a transverse window. By moving the window upwards and downwards the distance (and thereby the amount of mercury present) between source and window can be varied from zero to a given maximum. An alternative design, employing a piston, is proposed in applications where the radiation is supposed to travel along a path inclined through more than a certain angle against the vertical.

B.P. 809,280. Fuel elements for nuclear reactors. J. H. Handwerk, R. A. Noland, D. E. Walker and Atomic Energy Commission. (U.S.A.)

By substituting uranosic oxide (U_3O_8) for uranium dioxide (UO_2) in the composition of the material normally used, a fuel element can be produced which is safe from distortion in operation at elevated temperatures (up to 600°C). Also, when used in low-power, low-temperature, water-cooled reactors no cladding is required, as the material is chemically non-reactive with water. The uranosic oxide particles are uniformly dispersed and embedded in aluminium or magnesium or a mixture of magnesium with magnesium oxide in a continuous phase, a bond being produced by surface layers of uranium dioxide and metal oxide at the interfaces of the particles.

B.P. 809,281. Seals. B. W. Bradford, W. J. Skinner and U.K. Atomic Energy Authority.

The composition and manufacture of a material suitable for use in moulded sealing elements operating under conditions involving rubbing friction with exposure to the vapour of uranium hexafluoride. The material consists of a mixture of powderized polytetrafluorethylene and powderized graphitic carbon (specially pre-treated), in equal amounts. The pre-treatment of the graphitic carbon consists essentially in degassing under vacuum and subsequent exposure to an atmosphere of uranium hexafluoride for a period of 24 hours at room temperature.

B.P. 809,416. Apparatus for detecting radioactive particle emission. I. A. Mossop, P. B. Fay, G. Packman and Atomic Energy Authority.

Reference is made to the method of monitoring the radioactivity of a gas within a pressurized apparatus by counting the beta particles emitted from the radioactive coating of a wire or tape which moves through the apparatus. The actual arrangement provided for the wire passing through a straight tube sealed eccentrically into a Geiger counter so that the beta particles penetrating the tube wall could activate the counter. Resulting from the motion of the wire or tape, this design presented various difficulties. In the improved form, described in the present patent, the wire is stationary, within the vessel. An envelope of a beta-particle sensitive, scintillation-producing phosphor is provided and a scintillation guide penetrates the vessel.

B.P. 809,584. Liquid metal purifier. Babcock and Wilcox Co. (U.S.A.)

The oxides are removed from the liquid metal (sodium, potassium, lithium, mercury, lead and alloys, and eutectics of such metals) in a vertically elongated vessel. Inside the vessel, a peripheral quiescent liquid "chamber" is formed by stationary liquid close to the wall of the vessel. The quiescent liquid is cooled to present a cold surface to the liquid metal passing through the centre and it thus promotes precipitation of the oxides in the flowing metal. A shell-and-tube-type regenerative heat exchanger is mounted on the vessel to heat the purified liquid metal by the hot contaminated liquid metal coming in.